Oral History Panel:
Interview of the ALOHAnet Principal Designers

Richard Binder, Chris Harrison, Frank Kuo, Alan Okinaka, David Wax

Interviewed by:
Robert Garner
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Weber: So, I'm Marc Weber at the Computer History Museum here on February 21st, 2023, and I'm helping Robert Garner interview a panel of distinguished ALOHAnet principals. We have Frank Kuo, who is the co-PI [Principal Investigator] with Norm Abramson, and then David Wax, Alan Okinaka, Chris Harrison, and Richard Binder.

Garner: Thank you for that introduction, Marc. So, first of all, I want to say what a great privilege and honor this is to be able to talk to you guys all at once. About a year ago, as part of my project looking into the history of the ethernet, I happened to be visiting the CHM with some ex-Xerox PARC people, and one of them, Ron Rider said-- when we're looking at the ALOHAnet exhibit, said, "The person I'm in the facility with is Frank Kuo. So that was my first contact, and then Frank, you knew about perhaps, that Richard that was in California. So, I was able to find Richard and then Alan, you were in Hawaii. I was able to find you on the phone, and then Chris, I was able to find you on the phone [there too], and then Chris, you gave me a hint to find David Wax because there are too many David Waxes in the world, being up in Washington.

So over the course of several months I was able to contact all you guys, and then we've had phone exchanges and email exchanges, and Frank, a couple of months ago said, "Hey. Why don't we do an oral history panel of these four guys? Because they did all the work. I mean they have-- it'd be important to do that." So, I followed up on Frank's suggestion and organized this.

For me, I started my project on Ethernet history thinking that I would just cover the period at Xerox PARC and after that, but how could I not leave out the inspiration of ALOHAnet? I mean, we know that the Bob Metcalfe read about it in the-- I have the thick proceedings, the 1970 AFIPS Proceedings -- read Norm Abramson's paper, which inspired him to write a paper that was published in the Sixth Hawaiian International Conference on System Sciences on his way to maybe control a slotted ALOHAnet when it starts to get too busy, and of course, he went on to actually adopt the random-access broadcast method at Xerox PARC, and then of course, later, by 1980, it became the Ethernet standard. I always thought it was interesting that the reports -- the ALOHA system reports are kind of this robin's egg blue, Xerox PARC reports are blue, and the Ethernet spec is blue. So there's a tradition of the color blue here, guys.

So, I thought, so I've talked to Frank a lot, and Frank, last month discovered his diary that he had written from 1968 or so to '69, and he went through it, and he and I talked about it for an hour and-a-half or so a couple of weeks ago. But I thought that it would be good, now that he has all this re-remembrance in details, if he could maybe talk about the origins or the beginnings of the ALOHA System project in that timeframe, and then after that, I've got just some idea questions to go through each one of you. We'll do that in order, and then we'll open it up to a group discussion at the end. So that's kind of the agenda. Frank, do you want to kick it off with your revitalized memories?

Kuo: Okay. It started in 1968 in January with the HICSS Conference, the Hawaii International Computer System Sciences. That was the first HICSS.

Garner: You started those, right? Frank, you started those.

Kuo: Yeah, Norm and I started it, and I was a first chair. Anyway, it was a big deal because everybody wanted to come to Hawaii in January. So, among some of the people that came was people like Howard Frank and Len Kleinrock, and they were members of the ARPANET project to begin with, and so they thought it would be a good idea to have the ARPA principal investigators' meeting. They have quarterly meetings to come to Hawaii after HICSS, and so they wanted us to provide a conference room, which we did in the Holmes Hall, and that started in say, mid-January, and all of the principles from the original ARPANET project came, and Norm and I were not members, and initially they didn't even invite us to be there, but we insisted. Since were the hosts, it would not be a nice thing to not have part of us there.

Garner: Frank, this was January 1968.

Kuo: Yes.

Garner: Okay.

Kuo: Okay, and so around mid-1968, they have a two-day meeting, and Bob Taylor, who is the head of IPTO, and Larry Roberts came, and a number of the principal investigators' meeting people came, and Bob Taylor then talked about the idea. The initial beginning of IPTO, which means Information Processing Techniques Office, which started in 1962, and the idea, the main goal was IPTO was to build a reliable, survivable computer network for the military. So the idea of survivable and reliable was very important, and so he talked about that, and then Larry Roberts, who was the program manager for ARPA, talked about the new ARPANET, and his idea was that it's a demonstration project to connect some of the largest computer-- different large computer networks together using ARPANET, and so he talked about that, and he then talked about the idea that he learned in 1967 in a ACM meeting in Tennessee, and he gave a talk about networks at that meeting, and at the same time, he met Roger Scantlebury from England, who talked about packet switching, and he talked about the fact that he learned packet switching from Donald Davies, and so that's the first time that Larry Roberts learned about packet switching. And so after the talk he and Roger had a long discussion about the fact that in the future, packet switching would be everywhere, and so Larry had to learn more about packet switching before he thought that would be the way ARPANET would go through. So, he spent the next month or two learning about packet switching and actually learned about Paul Baran's work, which was done in California, but it was a project that was a military project.

Garner: Was that the RAND Corporation?

Kuo: Yes, RAND Corporation, but he could get access to that information. So as a result, in January, he told about the packet switching and that that's the way things are going to go with ARPANET, and so I thought-- in that two-day meeting, Norm and I learned both about ARPANET, which we had never heard about before and packet switching, and so we decided that we would do our own network. We were not invited to join ARPANET, by the way, and we would do our own network, and we would use packet switching. But we would not use landlines because we thought ~~that Hawaiian Electric's~~ Hawaiian Telephone's landlines were too expensive and also unreliable. So, it was sort of a natural thing and the fact that we in Hawaii have different islands. So, the goal was to perhaps connect all of the computers,

which was many computers, with different islands to the University of Hawaii IBM 360/65. So that was a goal, just like ARPANET, but with radio.

Radio was the main idea, and so for the next six months, a group of us, with Wes Peterson, Tom Gaarder and Shu Lin, we met quite often to talk about the difference between radio and landline and the fact that we only have one or two channels, and we also talked about the fact that we could not use the IBM 360 to do the packet switching, so we needed a minicomputer to do that. So, I think Norm and I were the two principles, but the others really helped, especially Wes Peterson in the beginning. But after it became a project, the others did not work too much, and then let's see.

We had to learn more about using minicomputers, and it turned out that in the summer of 1968, I went to an IEEE awards board meeting, and I arranged to go to BBN in Boston, in Cambridge, to meet with Frank Heart. So Frank was very friendly, and he introduced me to Bob Kahn, who was the real manager of the project. Bob and I knew each other at Bell Laboratories where he worked briefly for a year or two after Princeton, and so Bob showed me about the IMP and I didn't know what the IMP was because IMP meant no meaning to me, and he told me what an IMP was. Okay, so I learned that. And so we had dinner together, and we became good friends.

So, I told him [Bob Kahn] about our project. He said that would be very useful to Larry Roberts and he knew Larry Roberts pretty well. So, in the September of that year, we had our ideas pretty well in hand, and so we asked Bob Kahn to connect us to Larry Roberts, which he did. And so we went to the Pentagon, and so we walked to the Pentagon, walked into the E-ring. At that time, there were no guards, there were no guards. So, went into the E-ring and found it pretty easily there. He was like-- the E-ring, by the way, is a top military people there. Then you go down to the D-ring, which is when I went, I had a place in the D-ring, which is pretty high, but then you go down. Anyway, E was a pretty big deal, and I didn't know that. So, we met Larry Roberts and Bob Taylor.

Bob Taylor was very friendly and Larry Roberts was kind of cool [reserved]. So, and then Norm and I pitched the ideas, and Norm started about the radio, and I talked about minicomputers, and they got pretty interested almost right away, and we went through about two hours looking in details. And so initially, Larry Roberts wanted us to have the project built by BBN. He said they did a really good job. They are really doing a good job with ARPANET. Why not have them do the same thing? It'll be real easy. And both Norm and I did not think that was needed, and we fought very, very hard.

Garner: Apparently Norm…

Kuo: But Bob Taylor was very amenable and Bob Taylor was Larry Roberts' boss. So that worked pretty well.

Garner: Frank, apparently Norm got a little defensive because there was an implication that you guys wouldn't be capable of doing it and Norm kind of put his foot down.

Kuo: Absolutely. He [Larry Roberts] didn't think too much about U.H.[University of Hawaii], and so we were very defensive, because when we went to U.H. in 1966 the department was a very small department and didn't have anybody. And so essentially we were the stars and we wanted to show that we could do something for Hawaii, and so we did!

By the way, he [Norm Abramson] went to-- he was coming from Stanford. He was an associate professor there with tenure, and I came from Bell Laboratories, which is a really major research laboratory too, so we had to show up something. And we were both theoretical people, we were. And so we needed to work with engineers to help us build this project. But of course, we didn't tell APARNET that we didn't have the capability at that time to do that, and this is why you guys are here because we knew that we needed you guys more than we needed anybody else. And, by the way, we did not have a radio guy in the department, and so we needed somebody like Dave Wax to come in to help us.

But anyway, we were very persuasive and they liked the idea of radio. It was really a great thing. So, before we left, Larry Roberts said, "If we give you the project, we want you to take the BCC-500 over to Hawaii and continue to build it together." Because apparently it was in a company that was going to go under and the BCC 500 originally came from Berkeley. Though it had really a lot of great starts, but it needed to be finished, and he suggested that we invited Wayne Lichtenberger to help build the project. And Wayne Lichtenberger, and Norm didn't know Wayne at all, but Norman and I-- Wayne Lichtenberger and I started as freshmen at the University of Illinois -- and so I've known Wayne for a long time and know how brilliant he was and how dedicated he was. So, I was very willing to bring the BCC 500.

Garner: Apparently, Mel Pirtle was a friend of Larry Roberts.

Kuo: Right. Mel Pertle. Well, some of the names go, but anyway, it went so smoothly. Within a few months, we got a project, and so we started, I guess early 1969 to be the project, and Norm and I were co-project managers, and I would be the project-- I would be the project manager, and we would both be co-PIs. And so we started that then, and then we started hiring people and learning more about how we're going to build this, and so it's up to you guys to do it. So I'm finished here.

Garner: No, that was great. That's amazing, Frank. You summarized an hour conversation into just 15 minutes. That was really nice. That's a remarkable story in how it all connects because that hasn't been really told before. So now I thought the next phase you would go through, each of you guys in order. But I probably won't give up on Frank quite yet. Your role as principal, it was more than just the PI role. I think, Frank, would you say that you did a lot of the management and organization and let's say, hiring students? Was that kind of your role?

Kuo: Yeah, well, actually, Norm and I actually hired most of you guys. Not just me. But I actually spent all the time working about the money projects, and I also worked with the theory and the project work, but Norm also did that. But he wasn't just a theoretical guy. He worked also with a number of you, and he also went surfing, and I never surfed.

Garner: He didn't hold it against you. All right, and about when did you leave University of Hawaii?

Kuo: When did I leave University of Hawaii?

Garner: Yeah.

Kuo: Actually, ’82, but I left several times to work with the Pentagon because I worked with the Office of Naval Research for a year in 1971, ‘72, and then I worked in the Pentagon itself with the office of-- I was called the Office of Professor-- not professor. I was called the Director of Information Systems in ’76, ’77. It all began because I was good friends with Bob Kahn and also I worked with the Navy in CPAC, so I was more connected with the military then the Norm was.

Garner: Okay, and then my last question.

Kuo: Yeah, and then in ‘82, I was still working. No, I went back to Hawaii, but half of my time was in Washington. So I spent a lot of time traveling, and in ’82, SRI offered me really a big job, and I was thinking about it. Maybe that would just travel half-- it would take half my travel down and that's what I did. I really liked working with SRI over the years and so that was the best thing to do. So I left in ’82, and I was 48 years old, and I gave up my tenure as a full professor in Hawaii, and we loved it, but we had to do something for my travel.

Garner: In 1972, or ‘3, you and Norm had time to do this textbook on Computer Communication Networks. You guys were the editors of this. [Holding up the textbook]

Kuo: Absolutely. It's so many-- oh, I can show it.[Holding up the textbook] I couldn’t show it. [Due to Zoom’s background processing]. Well anyway. Yeah, it was Prentice Hall and it had all of the ARPA people contributing.

Garner: Then in ’81, you did this book: [Holding up textbook “Protocols and Techniques for Data Communication Networks].

Kuo: Right. I did a lot of books. But I’ll tell you, the two project-- this project and two of my books are the things I'm really proud of.

Garner: Okay. All right. So thank you very much, Frank. That's amazing. So I thought what we could do now is go in the order of Richard, David, Alan, and Chris. Richard, do you want to go first and talk about how you got involved in the project to begin with, and how that all started?

Binder: Okay. Well, I had decided in fall of 1968 to go back to school and get a master's in computers since that looked like a good field to move into, and so I proceeded to do that in September or so of ’68. Had a class with Norm in something. I can't remember what it was, and also had a class with Frank later on, and around-- well, in late spring of ‘69, Norm asked me if I wanted to work on the ALOHA project, whatever that was. I had no idea what it was going to be all about and so forth. But so I said sure, and so the summer of ‘69 I was on it full force. I was a student for about two years or so. It may have been three because I stayed on for a while do something else, and then became fulltime on the project around

maybe ’72, somewhere in there. So that’s how I got into the project, and then I worked that summer of ’69 really under Frank directly, who guided me, and what I was asked to do.

Garner: What did you think the goals of the project were at that point?

Binder: Oh, I can't remember if somebody said these are the goals of the project. I’m sure they did, but first exposure of the project was at the beginning of the summer of ‘69. There was a project meeting. That may have been the first full project meeting with all the different students onboard and so forth. There were three or four others, Charlie Bass, John Davidson, two or three others I think, and so there was a meeting to talk about the project, and the memories I have from it are Norm giving a presentation of a curve that he had developed, which appeared in the 1970 paper on the behavior of random accessing channel, including its congestion, and instability points, and so forth, and talked about that, and that was most of the meeting I think, the discussion of it. My first task that I was subsequently asked to do…

Garner: Can I ask you a question there?

Binder: Yeah.

Garner: Yeah, it's interesting. You do recall that on very first meeting he understood that the network could become locked up at a stable point. Yeah, but he never wrote about it in any of his papers.

Binder: Well, he maybe avoided writing it in-- talking about it in the 1970 paper. He did include the curves.

Garner: But they always cut off, right, when it starts to [decrease in throughput and lock up]…

Binder: He’d stop it right at the max point of goodness. But at that meeting, he talked at length about the instability of the channel, the bi-point operation and all of that. So, in any case, I proceeded as my first task. I was asked to design the positive acknowledgment protocol for the channel, and I think it may have been Norm, handed me a paper from Communications of the ACM by, I don't remember who, on the 01-bit protocol, [positive] acknowledgement protocol[Ref1] and I proceeded to implement that, or design it in detail for the system. It was actually a special case of go back N, a mod 2scheme. But at the time, they just called it 01.

And then proceeded to also design the packet formats, the rest of them. There wasn't much else in the way of protocols that time other than the random accessing, of course, channel itself. But I proceeded do the packet formats in conjunction, as I recall, with Alan Okinaka, who was designing the TCU, and we wanted to make sure the bits in the header were reasonable for him to be dealing with in the right place, and so forth in the hardware. So, let's see. I did that, and then also, at some point during that summer, I guess, probably Frank introduced me to the HP 2115, which was going to be the Menehune, the central controller for the channel, and I was tasked with developing the software for the Menehune. So I proceeded, and also I think Frank had asked me that first summer to pull together bits and pieces of what

Alan was doing, what the guys on the 360 side, Davidson and Charlie Bass were doing, to write it all up in that first document in ’69, Multiplexing in the ALOHA System.

Garner: Which you found a copy of in microfiche somewhere.

Binder: That's right. Dug that out and now online. So, I did that and that's “how I spent my summer vacation” was the first report that I wrote up.

Garner: Before you go on the summer, you mentioned that you may have had some memory in that first summer meeting of some student suggesting the name ALOHA.

Binder: No. My understanding is that somewhere I've seen from either Norm or Frank's oral histories or wherever it was that that came from Wes Petersen, but I don't know. It was pretty much a given I think in ’69, as I remember it, when I got involved in the project.

Kuo: I looked in my diary and I didn't find anything about ALOHAnet or anything like that, and maybe it was developed, it was thought about at that time, but I didn't write it. I didn't write it down, so I don't know when it happened.

Binder: Yeah. Well, it was called the ALOHA System. In fact, it wasn't until maybe a couple of years later, I started pushing to use the term ALOHAnet because I thought that was a much sexier term than ALOHA System. Norm always liked ALOHA System and used that, but in that fall of ’69 writeup that I did, we did use ALOHA System, and I think I even spelled out what the acronym stood for in that report, so somebody fed that to me.

Kuo: Yeah, it was ALOHA System. ALOHAnet came afterwards.

Binder: Right, and then of course, I continued to be a student for a couple of years, particularly those first two years, ‘69 and ’70. Once the summer was over and classes started up again, that was my primary concern. As I got into programming the developing software for Menehune, that started sucking my time,it was hard to not be doing whatever my class demands were. But it was otherwise pretty much summers for those first two or three years.

Garner: By the way, just to go back to that name again. So in case people forgot that later someone forced the name Additive Links Online Hawaii Area System.

Binder: Well, that was around by the time I wrote that first report at the end of the summer of in ‘69 because it's spelled out in that report. So I don't know who. I don't know where it came from.

Garner: Someone made it up. Yeah.

Binder: Yeah, go ahead.

Kuo: I thought it came from Wes, but I'm not sure.

Garner: Okay.

Garner: So Robert, I don't know how much further you want me to take this at this point. I continued to-- well, once I developed the software for Menehune, did you want me to talk about that?

Garner: Yeah. Talk about that a little bit if you could. I have a question there too.

Binder: Okay. Well, as part of the project, Wes Peterson guided a grad student in writing a compiler for the project for the HP that I am pretty sure was a subset of PL/1, since that was IBM's dominant language at that time for their stuff.

Garner: Didn't HP have a language you could use already?

Binder: I knew nothing about computers. This was a minicomputer. Okay, and by the way, it had 16-bit words and a whopping 8k memory size, and that's what we…

Garner: That's big actually, from that time. Yeah.

Binder: 8k, right. Well actually, two, three years later when the Menehune was-- when a 2100 was obtained to replace that with, it had about 32k I think, so much larger. So, I wrote the software, proceeded to debug it using the Teletype. One of the very nice things that happened was, as part of bringing up the interface between the Menehune and the IBM 360 TSO, timesharing system [option], a part of that TSO interface for ALOHA had the capability of downloading the programs directly into the Menehune through the IBM Interface machine to something that connected the two up. So we were operating through an IO channel provided by IBM, the standard IO stuff [IBM 1827 Data Control Unit]. That was connected between the Menehune IO ports and the 360 for which John Davidson was-- while I was writing the HP code, John Davidson wrote a module to reside within the 360, which provided ALOHA interface to TSO proper in the 360. Charlie Bass was also involved in this, but I'm not sure what-- how much his fingers got dirty in that particular place, but he and John both worked on the 360 side of that. But John in particular wrote that software to multiplex the ALOHA users coming in through packet switching through the HP into the 360, which of course, knew nothing about packet switching or multiplexing lots of users coming in through this single pipe.

So, let's see, and so the downloading of the program was really a very important thing because even though I still had to work with punch cards, lots of fun to-- dropped them once. You never do it more than once.

Harrison: Don't forget the paper tape.

Binder: Huh?

Harrison: Remember the paper tape?

Binder: Yeah, but I don't recall ever working with paper tape because we had this download capability directly from the 360.

Harrison: But, I recall initially you used paper tape to load the IBM boot capability into the HP computer, after hand loading the loader to read the paper tape. I recall you got unhappy when the boot load disappeared in high core.

Binder: Probably had to do that. Yeah, I don't remember it. I have no memory at all of touching paper tape. I do remember the punch cards and of course, printouts of the program, debugging and all, and then finally having it ready, and downloading it into the HP.

Garner: So Richard, you were way ahead of your time. Just the idea of downloading the software is only something that came to the rest of the industry much later.

Binder: Yeah. I don't know who was responsible for actually deciding to do that. Probably Wes Petersen is my guess.

Garner: It was very innovative for the time, very innovative actually.

Binder: Yeah, but it allowed some very fast turnarounds. Paper tape would have been…

Garner: Well, that's what the rest of us were doing on minicomputers, DEC tape, paper tape.

Harrison: I was involved in some of that also, because [when I was working for Geophysics with Noel Thompson] I went, on the Kana Keoki [research ship], and in preparation made a download program that would download their satellite nav program from linktape, and that eliminated feeding paper tape into the HP machine, a 30 minute load to reestablish the satellite satnav network. Using this process we were able to do the reload in seconds. So downloading, ALOHA System did a lot of machine to machine transfers. I did it, and Dick did it, and as I'll explain later on, I did it with the Aloha PCUs and the repeater.

Garner: Okay, great. Okay, let's hold that. So Richard, I've got a question. So, in your multiplexing report, remember, I found this section where you were considering a corner case, where if the-- remember, everyone knows [that the ALOHA System had] two separate [radio] channels: the Keikis, or the terminals, had one frequency going up, and then Menehune had a different frequency going down. So if the Menehune was-- sorry, if a Keiki was sending a long packet to the Menehune, and the Menehune was sending a short packet to another Keiki, if the Menehune was going to-- sorry. If the Keikis were going to acknowledge back to the Menehune, their acknowledgement would collide with another Keiki and immediately cause a collision. So you decided to not have Keikis send ACKs, which kind of makes sense because it [the Menehune-to-Keiki channel] wasn't a shared channel anyways, but you were going to keep the carrier up, kind of like a busy tone.

Binder: Yeah, I'm not even sure if I got into the carrier and I think Dave is the elaborator on that with a better idea. But yeah, as I pointed out, in fact, even in the introduction or abstract of that report that we decided to keep [out] acknowledgments from users back to the Menehune, to hold off on that, and leave that as a subject for further research because it was clear that that was going to mess up the channel if we started doing that, and yeah, as part of writing that up, I threw out some little idea about we could play a supplemental scheme but that was part of a much larger research topic, which we didn't actually follow up on. We never, in my time there at least, implemented an acknowledgement scheme for that. I think there was some that happened with Chris'- what was the name of the programmable…

Garner: PCU.

Binder: PCU, yes, for downloading files into the PCUs, for example, but that was not part of the ALOHA channel stuff then.

Garner: I think you made the right decision on having the user Keikis not send back ACKs. I mean that was the same decision that Metcalfe made later in the Ethernet. I think a lot of people forget that the terminals were transmitting on one frequency, receiving on another, so they really couldn't do carrier detection because they'd have to add a second receiver.

Binder: Right, yeah.

Garner: So that was out of the question. So you had to do acknowledgments or the lack of acknowledgement to detect collisions, so you couldn't do carrier events, and you couldn't collision detect any other ways.

Binder: Yeah. Well and that was all very deliberate because the goal was for that first implementation to implement Pure ALOHA, unslotted simple ALOHA, where if the user has something to send, he sends it, so we had to really have separate -- and also we had the much heavier flow of traffic coming back from the 360 as well, another factor. So we really needed the two separate channels. At the user terminals, TCUs, they did not need to be full duplex, and they were in fact half duplex, I believe. But at the Menehune, it really had to be full duplex with those two frequencies in order to do simple ALOHA at that point. Otherwise, we're talking about time division stuff in a single channel and it's a whole different ballgame. So, Norman coined a phrase at some point, and maybe a few months after that, at some point early on about calling the system "three-quarter duplex," but that was kind of shot down. It didn't catch on at all.

Harrison: Let me add that when we came to the repeaters, that was truly two channels, and the repeater had to repeat both on the broadcast channel as well as the incoming channel. So that process was of interest.

Garner: Yeah. Well, that led Richard to have to put a large gap between Menehune transmissions, so you wouldn't step on its next transmission.

Binder: Sure. Well, the Menehune actually, the terminals themselves were dumb. The TCUs, which is what we're talking about in the original context here, were all hard-wired and expensive to throw in different functionality, so the Menehune was responsible for spacing packets to the user terminals such that through the TCU, so that any timing considerations that the dumb terminals required-- I don't mean that disparagingly-- they were dumb terminals-- would work properly. In fact, there was what-- and after I don't know how long it was, a couple of years. I think originally, initially we had just the Model 33 Teletypes. But then those were suddenly replaced for a lot of people with dumb CRT terminals, which were blooming at the time. This was what? ’71, ‘72 timeframe I think, maybe ’73.

Harrison: Very expensive.

Binder: Yeah. Plus I remember there was this one unique terminal pretty much in the original system that was a graphics terminal, and it was Wes Peterson's baby I think, or he had…

Wax: I remember that.

Garner: The IMLAC.

Harrison: Yep, IMLAC. Norm had high interests with this early primitive graphics system.

Binder: Wes really wanted to use this thing. So the Menehune fed data over to that, and it had, of course, its own special timing characteristics as well, and the CRT terminals had their timing characteristics different than the teletypes. So and the Menehune had to be responsible for all. It was not a really big deal, but it had to have some tables and stuff and do that bookkeeping. So that’s where we’re at.

Garner: You had to basically implement flow control based on the type of terminals. When Bob Metcalfe visited later in ‘74, he commiserated with you because they had discovered the same problem at Xerox PARC between Novas and Altos. If you didn't do the flow control just right, the Altos would miss packets, so I think he was commiserating with you, that you had discovered that already.

So I have one more question for you. You told me the story about how-- speaking of Metcalfe, how when you visited at Project MAC one time, you might remember the date because you got a postcard. Can you relate that story again?

Binder: Yeah. Well actually, I meant to look up that postcard because it has the month, and date, and year on it that I mailed it back [April 5, 1972]. That's when we were back there. Let's see. The context was that Norman asked me to go back and give a paper at some local regional IEEE [Communications Society, ComSoc] meeting up in New York in the Catskills, I think, on his behalf because he couldn't do it, and I convinced him that John Davidson ought to go with me. John and I were fellow grad students, and we worked together a fair amount, took a number of classes together, and the objective was that after being up there and doing that, we would stop at BBN on the way back and pick their heads to learn good stuff about what we were doing out in Hawaii. So we did that, and while at BBN, David Walden was showing us around, and he took us over to the MIT Multics lab to show us that, and as we're walking

around through the lab by the carrels, Bob Metcalfe is sitting at one of the carrels reading my 1969 ALOHA multiplexing report, and with its nice blue cover and everything, and so I of course, got a big kick out of that. Here's my report from Hawaii in the MIT lab being read by somebody. Now why do I think that was Bob Metcalfe?

Garner: What was the date again then, do you think?

Binder: I believe that was in early '72. I didn't go back and look at the postcard, but I believe it was early '72. I'm pretty certain it was 1972. [April 5th] Now actually, Dave Walden might have set that all up just for laughs, but I don't think so.

Garner: Yeah. Because Metcalfe's story is he didn't learn about it [ALOHA] until he was handed the report by the IETF guy at his apartment in Boston.

Binder: Steve Crocker.

Harrison: Steve Crocker.

Garner: Steve Crocker. Yeah.

Binder: Yeah. Well, I might be mistaken. It might not have been Bob Metcalfe sitting in the Multics lab.

Garner: Yeah, I'll ask him.

Binder: They did have him around at that point in time, and but in my head, it was Bob Metcalfe, and I think because Dave Walden introduced him as such. Otherwise, I don't know.

Garner: I'll definitely run that by him. All right. Well anyways, I really appreciate all the documents that you've been able to find and make available and answering all my questions over the last year. Should we move on? Is that good for now? Okay, we'll get back together again. All right. David, do you want to take it from the top about when you joined and what do you think your role was supposed to be?

Wax: Yeah. Can you hear me okay?

Garner: Yeah. Great.

Wax: Well, I was finishing up some graduate work for my masters in the fall of 1968, and when they put the PhD program in the EE department, they added an option for the master's program. It used to be you had to write a paper, you had to do a dissertation. And when they started the PhD program, they allowed you to do just an oral exam, and 12 hours extra coursework, graduate level coursework. Well, since I was a working guy at that time, that was an obvious thing for me to do, and so I was finishing up my last hours in the fall of 1968, and I was working for a company called LTV [Ling-Temco-Vought]. They're a big aerospace conglomerate and they had a little research lab or research center there in Honolulu where

they were supporting the Navy on antisubmarine warfare and I was working on a lot of underwater acoustics analysis and stuff like that. So I took a leave of absence to finish up that last-- I guess that was a semester, wasn't it, at U of H, and so in preparation for taking my masters, and so I did that.

And then I had my oral exam in January of 1969, and Norm Abramson was one of the guys on the committee who did my oral with me, and actually, I specialized in automatic control. I didn't specialize in communication theory. But I'd taken a couple of classes from Norm. I took his course in communication theory and also one on coding theory and found 'em really interesting. He is a great teacher, and so anyway, after my orals were over, Norm approached me, and during the orals I had sort of explained that I was an experienced engineer, been working as an electronics engineer since 1954, '55, and I had a fair amount of experience, a little bit with Boeing, and also a quite a bit with Honeywell in Seattle.

So anyway, he was sort of interested that I had this background. I was a design engineer. I knew how to do circuit design and everything, and so after my oral was over, he approached me and said he's got this project that he's wanting to get going, and he called it the ALOHA System, and would I be interested in joining it, and at the time, I said, well, I can't really because I'm on a leave of absence from LTV, and I got to go back to that, and I was on a regular engineering salary and things like that, and I had a family to support. So I said, I'll go talk to my boss, and so I went and talked to him, and turns out that the money was winding down from the Navy, and they were going to be closing up shop. So that sort of set the decision for me, and so I went back to Norm and said, yeah, I can come onboard, and he said, "Well, I'm getting some more money in from ARPA." I think you were actually funded on Air Force money at the time, as I remember. Was that right, Frank?

Kuo: Yeah. Air Force money first. It's called THEMIS.

Wax: Yeah and then you got the ARPA money.

Kuo: Right.

Wax: Yeah. Well Norm was-- I guess he was pretty certain you were going to get the ARPA money, and so he said, "Well, I'll set you up with a regular salary equal about what you're doing now," and I said, "Wow, okay," and so I started in September of 1969 was when I came onboard to the project. I don't know. What was it? About a six-month lag there from the time I took my masters until I reported onboard,

And Norm, he had sort of explained the basic idea of ALOHA to me. I thought was sort of really interesting with the random-access channel. He told me it's going to be a two-channel system, and it made a lot of sense to me, and really what he was interested in of course, was the random-access channel, which was the whole thing about multiplexing many computer users onto a single radio channel.

So he wanted me to figure out how we were going to do the radios and the modems, and so I sort of looked at it, and I sort of saw that it was very similar to what we have in regular mobile radio communications, and so I thought-- oh, yeah, and the other thing was that Norm really wanted to get the system up and running as soon as he could. He wanted to demo it, and so I figured well, we'll just adapt

some mobile radios just to get this thing going. Back in those days, they were all, what, all tubes, and I bought a couple Motorola base stations, and first we had to hash out what band we were we going to get, and of course, we're asking for 100 kilohertz bandwidth channels, and of course, the FCC just said, “What?” Because you do not do mobile radio on 100 kilohertz channels. Well at UHF, they allowed you to have 30 kilohertz. Well, 25 kilohertz spacing, I think it was. Over the years, it kept going down, and down, and down as they tried to pack more channels in. But there were radios then that had 30 kilohertz IF bandwidths.

Garner: David, before you go to the radio, did-- the frequencies that you guys selected, 407 and 413 Megahertz, Larry Roberts had something to do with that, asking the military for those frequencies?

Kuo: They were Air Force military. They were Air Force.

Garner: Air Force.

Wax: The Air Force. I thought it was ARPA that got them.

Kuo: No, it was the Air Force.

Wax: Really? I didn't know that. I thought Larry Roberts was the one who got them for us.

Kuo: No. We had a THEMIS project with the Air Force and we got some projects there.

Wax: I didn’t know that.

Kuo: Yeah.

Wax: Well originally, we went into the regular UHF mobile band, and of course the FCC went, ha, ha, ha, and so that's when ARPA or Air Force came to our rescue and said, okay, we can give you these government bands in the 406 to 420 megahertz band, and so that's how we got it, and then they gave us a couple frequency assignments, and I don't know. Do you remember when that happened, Frank? I don't remember it clearly. Around ’69, 1970 maybe. It must have been.

Kuo: Around ’70, I think.

Wax: Yeah, I think it was. So that was my biggest concern was just getting frequency assignments.

Garner: But once you got them, as I understand, the frequencies were so close that you had to buy a high-end Lenkurt unit that could handle it.

Wax: Well, if you want to run full duplex, you got to have some pretty darn good equipment. That spacing was only, what, about six megahertz or so, six or seven, and at UHF, that's not easy to do.

Garner: So you mostly had to buy a large rack-sized Lenkurt for the Menehune.

Wax: Yeah, for the Menehune, I knew that I was going to have to get a common carrier quality radio, and Lenkurt was in the business of making them. I knew Lenkurt because they supplied a lot of equipment to Hawaiian Tel, and so I know the guys at Lenkurt.

Garner: This was a tube-based unit.

Wax: Oh yeah. Well, the stuff was sort of getting a little hybrid about then. They were getting some solid-state stuff into the radios, but all the power stages and everything like that are all tubes, yeah. And so Lenkurt -- that's why those radios cost us so much. That tight spacing with 100 kilohertz wide channels, Lenkurt did that, and because, just keeping the transmitter power out of a receiver, you've got to have some really super-duper diplexers in the front. So, they did that. And of course, the common carrier people like Lenkurt, that's their business building these very linear channels, radio channels, and you don't want to generate any more intermodulation products than you have to, and any nonlinear aspects in there will do that. So, for the full-duplex requirement at the Menehune, I went to the Lenkurt. We didn't have to do that for the Keikis though, because we could do half duplex for that, so we didn't have to transmit and receive at the same time, but the Menehune had to do that. So, it got the expensive radios. I think we bought three of them, and I think, Richard, you had one of them, I think, hooked up to a minicomputer, as I remember. It was a long time ago.

Harrison: Lockheed SUE].

Wax: What?

Harrison: Lockheed SUE machine.

Wax: Oh, yeah, that's right, and then the other two were used at the Menehune. One was hot, and one was in standby, so that we could maintain the channel. And then, of course, the first time we went on air, I used a modified Motorola base station, and of course, that's push to talk.

Garner: You mean in the user terminals or are you talking about in Menehune?

Wax: No. Oh, pardon me. I'll take that back. We did have-- we didn't have the Lenkurts yet, so I used a regular push to talk base station at the Menehune, and for a while there, Richard, you had to operate on the basis of-- you couldn't operate on a full duplex basis because I couldn't give it to you. But we only had the Menehune and a Keiki [at that time], so that wasn't any great problem. I mean, but I remember, you had to jigger up your code, so that we could do that.

Garner: What about the Keikis now, David? What were the first radios on the Keiki stations?

Wax: Well, the first Keiki was a Motorola push to talk radio, as I said.

Garner: On the user stations I'm asking, on the Keikis.

Wax: The user…

Garner: Same radio you're saying.

Wax: The first radio just to get the system up and running was a Motorola base station.

Garner: Okay, so you're saying including for the TCUs, but okay, what was the second one for the TCUs then?

Wax: Then after that then came the TCUs and we didn't use the Motorola. I mean, yeah, we didn't use the Motorolas very long. It was only a few months until we could get other equipment in and then let's see. I'm trying to remember.

Garner: In the TCU, did the radio unit go into, as one of the cards in the TCU, or was it external of the TCU?

Wax: It was built into the TCU, as Alan will probably remember.

Garner: Okay and did you design the modem as well, the card for the TCU?

Wax: Yeah, the modem was one of the TCU cards. There were five cards in there. Four of them was Alan's logic, and the fifth one was the modem, and then against the backplane, in the back of the TCU, we mounted the RF equipment, and some solid-state RF equipment was coming out about then, and I was able to buy it, buy the pieces and get the power amps, and the IFs.

Garner: So you bought those as separate stages and assembled them in the back of the TCU.

Wax: Yeah, we bought them as separate pieces and put it together.

Garner: I know you have a complete report on it. I'm just doing this verbally. I've seen the report.

Wax: Yeah, there's a report describing it. I don't want to go into all that gory detail. But we did. We bought pieces, and we made some of our stuff, and we bought some of our stuff. Because for instance, the IFs, I was running pretty high gain in the IFs, and so I did a double conversion on that, and I bought just a standard FM strip, it was a solid-state design. And then I designed a special 30-Megahertz first conversion amplifier, and then we dropped down to 10.7 Megahertz, and when you do that, you can keep the IF stable. Otherwise, you start getting so much gain in it, the thing will sing on you.

Garner: Now for the modem, can you talk about the modem design?

Wax: Yeah, actually, the modem design was influenced by chance and by stuff I learned from Norm. When we did the original setup with the Motorola base stations, I had to have a modem. We're running FM, that's the modulation that was available in those radios, but I had to figure out a way to handle the data. And I could have gone to like frequency shift keying or something like that. But the problem is there are other decision levels that have to be made. Because if you're using the FM or something like that, if you're using FSK, you've got slicing levels that you have to worry about. You have to worry about DC offsets and all this kind of stuff. And it was -- the crystal oscillators were nothing compared to what we have today. They were good, but they just didn't have the accuracy that we have today, and so I had to worry about the offsets out of the discriminators. And so I decided to just do an end run about that and use a subcarrier in which we could just AC couple and not worry about that, and it was just really practical stuff just to get us up and running.

Garner: Did the next version use Phase Shift Keying?

Wax: Pardon.

Garner: Did the next version do Phase Shift Keying? I always thought that you did Phase Shift Keying, Differential Phase Shift Keying.

Wax: I was talking about FM for the RF modulation.

Garner: Okay, what about the…

Wax: The reason we went to differential bipolar Phase Shift Keying data modulation was, once again, expedient. There were a number of manufacturers putting out wireline modems that were using DPSK, and so I bought a couple of them. Put one on the Menehune and put one on the Keiki, the originals, and they worked pretty good, but they were designed for wireline, and they're somewhat error susceptible. So, I figured I was going to have to improve on that.

So when we did the TCU, I designed our own modem, and that was designed to protect the data as much as I could because the way the TCU operated, well, the way the Menehune and the TCU operated is that the first “1” bit you sent was the beginning of the packet, and you have to worry a lot about false alarms for noise when you're doing that, otherwise, you're sitting there in check all the time. So I had to design the modem with a receive gate on it, and so I had to be able to detect when I got the modulation, the 9600 Hertz signal, and so I don't want to get into all the details, but we used phase lock loops and stuff like that to detect when we had coherency, and then I'd send a signal out to Alan and say, okay, it's all yours. But I wouldn't release it to him until I was sure the channel was down to-- I think I set an error rate about 10 to minus 5, or 10 to the minus 6, something like that.

Garner: Wow. Okay. All right. Well, that makes me think of a question.

Wax: You have to do that. Otherwise, the TCU would be sitting there checking the channel all the time.

Harrison: Yeah Dave, you may want to mention something about the carriers coming and going and the challenge of synchronization of the incoming bits, and how many bit times it took to synchronize, and so on.

Wax: Yeah, the subcarrier approach allowed us to do synchronous, and when you do synchronous, you can do a lot of good stuff. Actually, I designed a digital version of an integrate and dump filter on it and based on a lot of theory just on what I learned from Norm, and so we were able to get pretty good performance out of that modem, and then we had phase lock loop in there to acquire the phase of the signal, and so since the TCUs were listening to the Menehune all the time, I could design in a very narrow band phase lock loop on that. So even if you got a disturbance, it very likely would not lose lock, and so that's-- later on when we got the repeaters, then I had to modify it for a fast-sync modem, which was basically what was in the Menehune. The Menehune had to be a fast sync modem. Yeah. Because of the burst nature of the data coming in. So we had to change the TCU modems a little bit to accommodate the repeaters. The fast sync modems could sync in about 10 bit periods.

Garner: A lot of challenges. Like I said, one last question. Do you recall ever like in a lab environment having two Keikis sending at the same time to your receiver on the Menehune to see whether you had a capture effect or to see whether collisions were actually detected?

Wax: Actually, with a pair of TCUs would force as a collision?

Garner: Yeah. Did you ever test that?

Wax: No, I don't think we did. Did we, Alan? I don't recall that we ever did that.

Garner: It could be that your receiver was so good that if one was-- even though they're both transmitting at the same time, if one was closer, you could have captured the signal of the closer one.

Wax: Now one of the things about using FM was the fact that you got capture effect. Actually, I got a double because I used not-- I did hard-limiting not only on the FM, I did it on the subcarrier too. So you got a real waterfall effect, and all you needed was about a couple dB, and you were error free.

Garner: So I think it's conceivable. I've said this. You guys can think about this, but I think it's conceivable. Since there are only about five or six TCUs ever built and PCUs ever built, that a collision may have never occurred in the airways of the ALOHAnet project.

Wax: I don't know if we ever did and I don't know. Richard, did you ever collect any data? I don't think so.

Garner: Oh, he's muted. You're muted, Richard.

Wax: You're muted, Richard.

Binder: That's what happens when you follow instructions.

Garner: You can stay unmuted.

Binder: Anyway, without some special aid through probably a separate interface from the hardware from Alan's [TCU] unit, or possibly via Dave, it was pretty hard for the Menehune to determine if there was a collision or not. The Menehune just had a 16 bit register with words coming in and an interrupt every time 16 bits came in, and then plus the checksums, both header and data checksums, and I forget what the convention was, Alan, that-- if the checksum in the TCU had checked bad, I forget if you wrote all zeros or something in it, something like that that told the Menehune that it was a bad packet.

Garner: How many checksum errors did you record?

Binder: We did certainly record that.

Garner: Do you remember getting any checksum errors in the history of the project?

Binder: I'm sure we did, but I don't remember it. But we had some counters in Menehune to collect simple stuff like that. But as far as whether a checksum was bad because of channel noise or a collision, Menehune really didn't have a way of determining that.

Garner: Okay.

Harrison: Yeah. Didn't your Lockheed SUE do a lot of simulation for collisions?

Wax: I thought you did.

Binder: Yeah, but that was not actively in the channel. That was simulated.

Garner: Okay, David, any more thoughts? We're going to move on, on the radio side of things. One question I had is, the thing always ran at 9.6 kilobaud, I believe. Norm tended to write 20 kilobits per second. That was like a goal.

Wax: Yeah, I know. Well originally, we were talking 50 kilobits per second, but we never got there because well, we had receivers that just didn't have the bandwidth, and we just couldn't handle that data rate, and actually, 9600 was about as much as I could reliably get through. These receivers, the maximum bandwidth on them was like 30 kilohertz. After we built our own receivers, the ones we used in the TCUs, we did build those for a full 100 kilohertz bandwidth, but we never changed the data rate. We just left it the way it is.

Harrison: Yeah and we never investigated quadrature encoding, or octal encoding, or higher levels of encoding.

Wax: Nah. I mean, my marching orders as far as I was concerned was to get an operating system up. I mean really, the random-access channel was what is to be proved, and I wasn't trying to come up with

any fancy modulation schemes. I was trying to build it with what we could get readily and get up and running, and I'll tell you. Later on, if we got funding and so on, we could go play those games, but at that time, wasn't interested in…

Garner: Yeah, well, the whole ARPA packet radio project went on for a decade later exploring that entire space.

Wax: Yeah. They're the ones that really looked at it and fine by me.

Garner: Yeah, it was a huge project.

Wax: Yeah, that's a real can of worms.

Garner: That's a real can of words.

Harrison: It's still being explored today.

Garner: Yeah, it was a massive project back then. It's good you guys didn't get sucked up into it. Okay, anything in last thoughts, David?

Wax: That was the greatest project I think I've ever worked on. I really had fun. Usually working for some company or something, you get deadlines and all this crap that you have to deal with, and so on. But this one was -- Norm said, here it is, go at it, and as an engineer, it was probably the most fun project I ever worked on.

Kuo: Where did you go after ALOHA?

Wax: I went back to Honeywell in Seattle and returned there. I didn't go back to the phone company. LTV was gone. They were only there for a few years, and so that was what I decided to do, and it was okay, and I spent about five years with Honeywell, and then I went back to Boeing, which was the company I originally worked for right at the start.

Garner: I think before you left, you worked on the ATS-1 project, right? Satellite, ATS-1.

Wax: Yeah, I forgot to talk about that.

Garner: That's okay. Just as a project you worked on.

Wax: Well, I've just got to mention, I think that was a project proposed by NASA Ames, I believe, but probably steered that way by Norm, if I know him. But it was really their project, and they built all the hardware and everything for it and shipped it out to us, and so we were playing games on that. We were experimenting. That was really interesting. Yeah, I found that quite an interesting project.

Garner: Yeah, okay. All right. Well, let's move on. Everyone's doing good. Alan, do you want to go next? When you joined, and what the goals of the project were, all that kind of stuff, what you did.

Okinaka: Okay. I came to the project after being in the Army as an electronics technician maintaining, installing, and repairing fixed crypto equipment. It's a highly classified piece of equipment, but at that time, the drivers-- it was like a hybrid cube and solid state. It was between the two. The bit memory was on a magnetic core about the size of your thumb, and there was a whole bunch of vacuum tubes in there. Huge power supply to generate a lot of power. We worried about everything from the proper grounding, shielding, all the way up, and my job was to maintain everything up until the information was passed over to the single side-band radio system that the communication center had. So, I had a lot of experience in putting packages together of different types.

And after I got my bachelor's in electrical engineering, I worked for Adtech. I don't know if you remember Ad Tech, but it's a company put together by Dr. Rohloff [ph?] and Dr. Weldon, Ed Weldon, and I forgot Rohloff's first name. But it was a truly garage electronic company and we had two products. One was an educational training system for Logic and the other one was for customized systems. The only one I can remember is they wanted a way to measure the reflex when somebody taps your knee to know whether that's a proper reaction or not. But there were other customized electronic systems that were put together by Adtech.

And when this ALOHA project came around, Dr. Weldon and Dr. Rohloff convinced me that this is something that my expertise was needed, and I could do it, so I got interested in it. So, I joined in 1969, about the same time as David. I think you were there already, David, when I came onboard. I understood what was needed. It was easy for me to visualize what the system would look like because I was familiar with a whole bunch of other electronic equipment. So putting it together was a matter of knowing what the system requirements were, like what the power supply output has to be, and how much power to shielding, and everything like that from the radio system. But the thing that I didn't know was that there was no such thing as a terminal control unit in the marketplace. That meant-- and I did a lot of research and there was nobody making anything like that. I couldn't go to a RadioShack, and pick up something, and slap it together. The microprocessors were in its infancy, right, and I think it came about in 1974, I think. Right, Chris?

Harrison: 1973.

Okinaka: Yeah, and so here we were in '69, and we had to use discrete TTL logic to put all these things together. The most sophisticated integrated circuit we had was a flip-flop, and so it was all pieced together. And it was a lot of fun because it's like coming to work every day and trying to think, okay, what new problem am I going to run into, but I enjoyed it. Interestingly, I don't remember why we did this, but they requested that we build an interface between the ASR, the Teletype ASR, the Teletype unit, and I'm starting to think that that was what Richard used to interface with the HP 2115.

Harrison: That's correct.

Okinaka: That's correct?

Harrison: Yes.

Okinaka: Okay. That was a daunting task because, as you know, the Teletype runs on electromagnetic coils and all that kind of stuff for their data. So to convert that into digital pulses reliably was a very challenging task, but we did it. We got that going. Then working on the TCU, the TCU was the buffer between the terminal and the radio system to packetize information. We had both full packets of 80 and half packet of 40 [bytes]. The header was 16 bits, and I think there was a-- we designed a polynomial of 16 bits to make sure the header was correct, and then another 16 on the data, so that the data would be correct.

Garner: Did Shu Lin help you with that CRC?

Okinaka: I'm sorry.

Garner: I think you told me a story that Dr. Shu Lin helped on the CRC.

Okinaka: Yeah, that was a fun meeting because we just sat down and he used all his-- we used his book. I forgot the name of the book. Frank, do you remember the name of the book that he wrote on error correcting codes?

Kuo: It was on coding theory. I asked him to write that and I helped him a lot.

Okinaka: So we used exactly what was in that book in order to design the circuitry to create the polynomial for error detection up until three bits, ideally. We could go up to three errors.

Garner: So this was Shu Lin's book, not Peterson's book.

Okinaka: Yeah, no.

Garner: Peterson had this book on error correction codes. [Holding up Wes Peterson's 1961Error Correction Codes, MIT Press textbook]

Kuo: No, that's an early book. Shu Lin worked for Wes Peterson.

Garner: So his first edition was this book.

Kuo: His book came out in Prentice Hall around 1970. [Introduction to Error-Correction Codes, Ref2]

Garner: Okay.

Okinaka: Yeah, in fact, I took a course from him, and so it was fun to take something out of a book and actually design something that would go into a system.

Garner: He said he really-- you said he recalled he really enjoyed that. It was three error detection and possibly one bit correction. But you did not do the correction part.

Okinaka: We didn't do the correction because the circuitry got kind of horrendous, and it would also delay to transmit the-- well, if there was no delay, it's fine. But if there was a delay for error correction, then it delays back sending that information to the terminal. So besides the TCU, which is really a buffer unit, I designed the-- I called it a concentrator, but all it was, a random-access scheme by hardware to a single TCU. In other words, you could put up to eight terminals, randomly accessing one TCU to get on the air.And we thought that would be a real practical way of using a single-- instead of having one TCU for one terminal, have eight terminals connect to one TCU, and we got that implemented. I don't think we had eight terminals connected to it. Put the repeater together and Richard probably…

Garner: I mean before you go on to the repeater, one thing I found interesting in your TCU design is your memory was a 640-bit shift register. There were no SRAM chips that you elected to use. You just said you shifted it all the way through.

Harrison: No memory chips available. The 2102 was the first reasonable size SRAM chip that came out and that was in ’73, ’74 timeframe. Memory was a big problem.

Garner: Yeah, so you needed to have-- you probably used a whole bunch of 8-bit shift registers. I could see how the chip count would go up.

Okinaka: The most sophisticated TTL integrated circuits at that time, so…

Garner: One thing I thought was interesting is that because you only had this fixed register, you guys called you would “lock the keyboard,” and now I realize that meant that you didn't echo back to the teletype. So the user may have been typing, but nothing was echoing back, so it would have the effect of a locked-out keyboard.

Okinaka: Oh, yeah. So you don't get it all mixed up.

Garner: Yeah. So, in essence, basically you had some good flow control method. Now the other thing that was interesting looking at your design, because David Wax had saved that paper you wrote back then, was that you only did two retransmission attempts.

Okinaka: It could be more, but I felt that after…

Harrison: Three.

Garner: Oh, it was three. Okay.

Okinaka: It could be more than that, but we just set a limit to that.

Garner: Then you had some kind of random pulse generator. What was that?

Okinaka: Yeah, we found this interesting circuit. I don't remember where I saw it. But we found one that generated random occurrences based upon some bad circuitry. If you use a bad capacitor, a bad resistor, a bad inductor, and it generates a crazy [pulse] sequence that never repeats [that was then passed through an amplitude cut-off filter, allowing only certain amplitudes to pass and be a pulse.] So well, and I can't remember what it was, but I thought it was a very novel way of getting random access information.

Garner: Up to about a second and-a-half, according to what I've seen.

Okinaka: Yeah. In our Army system, we use the Fibonacci chain, and the Fibonacci chain was programmed with a set sequence of ones and zeros to start off at a different location, I mean, a different initialized set of data. And as you probably know, the Fibonacci chain will take that one set and then generate random pulses. This one here was a bad-- it's a bad electronic circuit that generated random pulses.

Garner: Why was there a need for randomness in the Army system?

Okinaka: Oh, the Army system had-- it's part of the encryption scheme.

Garner: Oh, I see.

Okinaka: Yeah, and it's…

Garner: I got it. Yeah.

Okinaka: They kind of warned us about what we can say and cannot say.

Garner: That's enough information. Yeah. Okay.

Okinaka: Part of their encryption scheme.

Garner: Right. Okay.

Okinaka: Then we put together that 50-kilobit line between the Menehune and the 360. It went through their NFA system. I can’t remember that. It was a humongous chassis, 18 something, 1830 [1827]. I don’t know. Anyway, it’s one of those IBM numbers, and that one there, we didn't want to pay for a leased line, so all we did was get wires between Holmes Hall and what was that that IBM was sitting in? Whatever. Anyway, in Holmes Hall.

Harrison: Geophysics.

Garner: Where was that Chris?

Harrison: Geophysics. Third floor of Geophysics across the parking lot from Holmes Hall.

Okinaka: Yeah, wherever that 360 was sitting. So, we just blasted that thing with high…

Garner: So did the wire go along the sidewalks or something?

Okinaka: It went through a-- there were conduits connecting the buildings.

Binder: By the way, I just wanted to add, the original system, that came later with 2100 in Holmes Hall, but the original system, the Menehune was located in the Computer Center, just outside of the 360 room, and so that wasn't a part of it then.

Okinaka: Yeah, when you moved the Menehune into the Holmes Hall, we had to have that wideband circuit over to the thing [S/360], but it was a very simple, no sophisticated protocol or anything. It just blasted the signal right through and it worked. It was cheap and it worked.

Wax: I remember, you did that-- what did you run, around 50 kilobits or something like that on it, didn't you?

Okinaka: Yeah.

Wax: Fifty kilobits per second, yeah. Yeah, just straight wireline and no compensation or anything.

Okinaka: No and it didn't—well, I think we were the only ones using that bundle for one thing. And the other thing is that, like I said, the transistor's drivers that we used were heavy duty ones. Yeah. I think they were designed to do that.

Wax: Yeah, they had those wireline drivers.

Harrison: And you used NRZI to avoid biasing the lines.

Okinaka: Overall, I had the responsibility of keeping the lab as the lab, hiring people, making sure we had the right equipment. Every year, we sat down and figure out how we're going to buy all these electronic parts. The University of Hawaii has a system where if you spend a certain amount, you've got to get three bids. Usually when you go with that kind of three bids, you can end up with a supplier that has inferior components, and then so that means that you might buy a hundred components, and 5 of them, or 10 of them would not be good. So we had to come up with three [bids].

Wax: Yeah, I've got a story on that one. When I bought those Motorola radios, they went over the cost threshold with the university's procurement department. And well, we ended up anyway, on paper, splitting those radios up into three parts, so we could buy each one separately to keep under the cost threshold to get away from the red tape.

Garner: That's a very common technique you see to this day.

Okinaka: It's been 50 years, so I'm sure they're not coming after us, but that's exactly what we did for a lot of the components. We split it up, so that we could get below the written bidding. It was a hassle for that.

Wax: It really was.

Garner: So, Alan, you were telling me that when you were debugging-- I don't know how long it took you to debug your TCU. But you were telling me that you were thinking you would like to have-- you contacted HP or someone for maybe some Logic analyzers.

Okinaka: Yeah. We worked with the local HP guy a lot because they're already kind of on the forefront of digital circuits and systems, and I wanted things like a bit inserter or a packet inserter, and we had a bit inserter in the Army. Only was a small little thing like a flashlight, and you connect one to ground, and the other one, you click it, and a bit gets inserted into one of the logic cores. I wanted something very similar to that and nobody made those things. I wasted my time going through all these companies looking for something like that. So we finally ended up making those things, and we made about three or four of them, and it's very simple. All you got to do is you touch your probe over on a flip-flop and you'll convert that one to a zero, a zero to a one.

Garner: Yeah, I've used them, and also you were looking for a logic analyzer of some sort, but they didn't offer one yet.

Okinaka: Well, it was more, I wanted a packet generator.

Garner: Just a generator, not an analyzer. Okay.

Okinaka: Yeah. We wanted to be able to key in a packet, and then insert that, and send it in, so that way you don't have to have a terminal and press the key.

Garner: Did they make one? Go ahead.

Binder: Well actually, we had such a device sitting there, the HP 2115 in that original system, which if I had been more savvy, I could have written a little software, and we could have used that. In fact, too bad Chris wasn't on the project at that point because it's probably right up his alley. But I remember you guys both debugging your hardware in that initial thing at the computer center. I'm not sure where your stuff was and we weren't making use of the HP at all, which we should have with hindsight.

Okinaka: Yeah.

Garner: Did they ever supply a packet generator for you at all?

Okinaka: No, they never did. But later on, they came out with a bit inserter. I don't remember. It wasn't very expensive, a couple of hundred dollars. I think.

Garner: Well packet generators became a big product for many companies, at least by the late 70s, 80s, by the early 80s.

Kuo: Not when we started.

Garner: Oh, but I'm thinking that you guys may have put the idea in their head.

Okinaka: Yeah, I suspect that's what happened with HP because, even like the bit inserter, about a year later, they had something like that, and so who knows? Like I told you earlier, we had no idea that some of the things we designed and built were patentable, and it was kind of frustrating for me to hear that some of the circuits we designed were actually-- somebody had patented it.

Garner: You said you got the TCU working in the middle of the night. You went out to have a celebration dinner and that was it.

Okinaka: Yeah. That was a fun thing because when the TCU first worked, my lab assistant and I were the only ones in the lab, and it was exciting because it actually did something, and so we went down to a Kunia saimin shop about 10:30 in the evening, and we had saimin, and that was our celebration. The next day, of course, we made sure Frank and Norm knew about it, but that was a really exciting moment. Of course, on the other side of that thing was there were a lot of nights that I sat there looking at the TCU, and knowing that if this damn thing didn't work, this whole project wouldn't work, so a lot of pressure.

Garner: Yeah, I think people forget how much pressure are on us engineers in those situations because it's easy enough to write about it and do simulations, but it's another thing to actually get it to work.

Kuo: Right.

Garner: So congratulations.

Kuo: I remember Alan played poker with Norman, and I, and other groups every Friday in other people's rooms, houses. I had somebody in my house and then Norm had some poker places in his house. You were a good player in those days.

Okinaka: Well, you came over to my place I know several times, and some of the real interesting stories out of it. Norm was the best bluffer I ever had. He can bluff you with a straight face so well and we got caught in the trap.

Kuo: Right. I still play poker once a month. I can lose up to $50, and win $50, and I'm told that I lose more than I win.

Okinaka: Very good.

Garner: So why do you think Norm was such a good poker face?

Kuo: I think he's an extremely clever guy. I mean, how did we win the project management from ARPA? It depends upon Norm a lot!

Garner: Yeah.

Okinaka: When you think about it, it's probably he got trained by convincing a lot of funders to fund the ALOHA project, and I'm sure there were a lot of moments when you really didn't know what he's proposing is going to really be funded.

Kuo: Right, of course.

Garner: Yeah, that's a great skill. Yeah.

Kuo: I think poker plays a lot of role in that.

Okinaka: Yeah.

Garner: It should be an undergraduate requirement. Okay. Any other thoughts, Alan?

Okinaka: The only other thing is ALOHA System was recognized by a lot of foreign countries, and for some reason, Frank and Norm decided that I would be the host, and so when the Japanese engineers came through, I had to sit down with them and patiently explain with their broken English and my broken Japanese-- well, I can't even call it broken because it's not even Japanese. But anyway, we had to do that. I was very proud when the first-time Chinese journalists from mainland China visited the United States, they decided that one of the things they wanted to see was the ALOHA System project. And they came over, sat down, and I found out-- I thought they couldn't speak English, and I found out they spoke flawless English. It was very, very embarrassing for me. I think I told people in our training; I mean earlier that, I thought if I spoke slowly, and I spoke loudly that my English would automatically be translated into other languages. But that was a very embarrassing moment. We had guys from either Hungary or Turkey.

Kuo: Hungary.

Okinaka: Was it Turkey?

Kuo: No, it was Hungary. Norm went to Hungary.

Okinaka: Yeah. We attracted a lot of attention, so it was worldwide, and widely known. We tried to convince the state of Hawaii, I believe, right, Frank, to fund our project, and it never took off. They didn't see any value in what we were trying to do.

Garner: Did you actually try to do that, Frank, actually try to convince them to fund a network?

Kuo: Not really.

Garner: You just gave up.

Kuo: I mean, we had so much money, we didn't.

Garner: But Frank, you didn't have enough to build like 50 stations around the islands, right?

Kuo: No. Actually, I wasn't really interested in that because I thought we were just a demonstration project, and we made it then, and we became famous because of that.

Garner: It was enough. Yeah.

Kuo: Yeah, that's enough. I mean, the stuff we built was huge. We couldn't put it all over the island.

Garner: Yeah, it would have been a much bigger project.

Kuo: Right.

Garner: Okay. Well, it's happened now. Here we are, 2020s, and here we are talking video from Hawaii to California.

Kuo: We haven't talked to Chris.

Garner: Yeah, Chris is next. Yep. Okay. Anything else, Alan?

Okinaka: No. Well, I should mention that we also worked with Lawrence Livermore Labs and the Stanford Research Institute. Lawrence Livermore Labs were interested in using our system to measure average wind velocity over a given area, and so they beamed a laser beam from Tantalus down to Leahi Hospital, and we didn't get very far with that because it didn't work the way they wanted it to. And the other one was with Stanford Research Institute, a couple of professors or engineers, I can't remember what their titles were, but they came down, and what they wanted to do is to have the remote capability of anywhere in gathering scientific information, and so the target was the Haleakala Crater, and that pushed us into trying to get a repeater up there. But we never were able to get a reliable path back to the 360. So that went as far as connecting up with an astronomy group, getting permission to set up equipment, use their system, use their electricity, but we never got farther than that.

Garner: Yeah.

Weber: Sorry. But you did go up there, I remember reading, right, to install something?

Okinaka: Yeah, we did go up there, and we actually hauled the equipment up there and tried to get it going.

Wax: I thought we did run some tests from up there, didn't we? I mean as I recall, we had a really very good path. But that wasn't from where you're wanted it, by the rim of it. That was actually brought from the astronomy building up there, I think, wasn't it?

Okinaka: Yeah, we used their utility building to set up.

Wax: Yeah. As I remember, I provided you a Yagi antenna for that. Yeah.

Garner: You had a good link from the top of Haleakala to the repeater in the hospital, but maybe some other aspect of the project didn't work out.

Wax: Well, then you had a link from there. You had a couple from there over to the-- well, you had the National Park building, which was right by the rim pretty clear.

Okinaka: Yeah. The Visitor's Center is right on the rim, and we looked at the bathroom building, which looked like we could have installed a Yagi from there back to…

Garner: So maybe what David's saying is the link from there to the Diamond Head Hospital, whatever the name of that hospital was, was okay. But maybe there was some other problem from the top of the crater into the crater or something.

Okinaka: Yeah, you got to be out at the rim because the crater drops very rapidly from the rim down.

Garner: Right. I'll be there in May, by the way, and I've been in that building you're talking about, and a friend of mine actually worked there for a while. Okay, we'll talk about the deployment when we have a group discussion about where all the repeaters and stations were, but let's move on to Chris. Chris, you still there?

Harrison: Yep. I'm here.

Garner: When did you join, and what did you think the goals were, and it's all yours?

Harrison: Okay, well, let me go back a little bit, and state that I'm kind of a technology freak, and before I went to elementary school, I was always interested in radios, elecronic components and so forth. When transistors became available I remember buying one on my way to school when I was in seventh grade. That was in 1958, and I got my amateur radio license back then in '59 and going on, moved to Hawaii in

1960 and attended UH after HS. At UH, I cofounded KTUH, and I became responsible for the technical side of KTUH, getting it on the air, and in the process of getting it on the air, I built some line power line carrier transmitters because we weren't able to broadcast FM. We had challenges with the UH regents to get our license approved. So to allow operations, I built some carrier current powerline transmitters and they were located in the UH dorms. Then we finally got a license approval from the Regents and I got my FCC first class commercial to support KTUH in ’68.

And then after I graduated at UH as an engineering student, Noel Thompson of geophysics got me very interested in amateur radio repeaters, and renewed my interest in amateur radio there, and I didn't know very much about FM two-meter repeaters at the time. The radio HAMs had a repeater set at Diamond Head, and they had also a repeater setup on Haleakala, and Mauna Loa, and they were all linked in the 400 megahertz band, and we were able to communicate with our handhelds pretty much anywhere on the islands over the islands. The links now have been terminated for everyday use, even though they're available in emergencies. The political people in control state: “We don't want the islands interacting with each other using radio communication. We only need it in the case of emergencies.”

So going on from there, I was working for Noel Thomson, the lead engineer at geophysics, and he had a SPC-12 minicomputer, and I got a chance to work with that and hand code, machine code. He had a Teletype machine, and he also got on loan a Hewlett Packard machine, a 2114 I believe it was for satellite communications they were going to put on the boat. So I got to play around with the 2114. I remember I had to hand code because the assembler was a three-pass paper-tape assembler, which answers one of the questions of what you could do back then. There was an assembler available for Hewlett Packard, but it was on paper tape. It was three pass and it was horrendous. So anyway, I learned how to code machine language with a simple editor I wrote.

And I also knew of the ALOHA system and learned more about it through friends. People mentioned the project it saying, “Oh, interesting project. Why don’t you go over there? You got talents. You know how to code. You know about electronics. You know about computers, minicomputers and so on.” My boss, Noel Thompson at that time, who hired me as a technician, even though I was a graduate engineer, he said, “Oh, I have a position available, interested, will you take it?” I said, sure, because I wanted to get my hands dirty. I loved the UH. I loved technology, and what was going on. So I started work at Geophysics. And so to make a story kind of short, Norm Abramson got word of me and said, “Oh, yeah, we'll take you on. we'll take you on. Come on over and help us with radio, and computers, and so on.”

And at that time, there was no microprocessors. Again, like Alan, I was playing with 64-bit shift registers, and most of them were dynamic, which means you had to keep shifting them or their memory would go away. We had flip-flops and various logic gates, and that was about it. But I had got the shift register from a corporation called Intel, and I heard that they had the 4004, and I looked at it, and oh, yeah, it's a calculator chip, a pretty nice little calculator chip. So, I didn't think too much about it, and whenI went over in 1972, about I would say March timeframe, and I moved from geophysics to the ALOHA project, and of course, I met Alan, and I knew Alan from before because we had a class together, I think, with Frank Kuo.

To go on now, I got interested, and I was kind of delving around looking at the TCU and the radios, and met Dave Wax, and Dave and I were talking about radios and so on, and having a good time, and I didn't really have any goals at that point, and Frank Kuo stepped in and said, “Oh, we'd like you to go to SRI in California,” and so I went, and I got limited training on the DEC 10 . But, I was really interested in Intel because I knew they had some pretty interesting stuff coming out. I heard about the 8008, and so I drove over there, and I just popped into the front office of Intel. I talked to them, and they showed me this little proto board, which had an 8008 on it, and I looked at it, and I said-- immediately lights went off. I said, “Hey, I can use this as part of a preliminary programmable control unit,” and so I phoned Jeannie in Hawaii, and I asked, “Can I get a PO to get one of these things?” and she worked it out. It was about $300, or something like that, or so, and I got to bring it back, and I sat down with a Teletype, made it talk.

And also, the another thing that came about at that time was Intel had just introduced the 1702 EPROM, which was a big memory deal, 256 bytes on a chip. Oh, my goodness. It was tremendous, and Alan and I were looking for memory, and there it was. Not only that, but it was permanent, static. It wouldn’t go away when you turned the power off. So I got some of these, and I sat down with a little radio. I don't think I had a radio. I had a connection to the 2115 at that time, and I connected up, and I made it talk serial to our 2115 computer. I was able to communicate with the 8008 protoboard, but the trouble was, it was too slow. I couldn't do any parity checking or anything. So I remember I just wrote the code, hand coded it just to pull the packet in and ignore the CRC check and just threw it on the Teletype, and it worked.

So after that, Dave and I got together, and we got a radio, had conjured up radio from somewhere, and we made that work, and I was reading up on Intel, and I reliazed, “Oh, they’ve got an 8080 chip coming out. It’s not available yet, but let's see if I can get an early one because it's so much better and faster than 8008, and the code is pretty compatible.” So, I wrote them, and we were able to get a sample chip for $360. I remember that price. It was very expensive, but we got one of them, and I was able to wire wrap up a board, but I needed memory. 1k by 1 were the biggest memories, power hog memories, I could get in a 16-bit chip, and got eight of those, and it eventually became times four to give me 4k of memory, which went away of course when you turned the power off, but I had four of those fabulous EPROMs at 256 bits each, and put four of those together to get 1k of memory, which was a big deal in 1973.

And from there, I was able to write code, hand-coded it, handloaded it, got it into the EPROM, and the way these EPROMs worked, if you made a mistake, you had to take them out, and you had to cook them for 30 minutes to erase the memory, and then you can put them back in and reprogram it again, and so you don't make too many mistakes. So what I would do is I coded a little bit of a boot loader, we called it that, into one of these EPROMS, and I loaded my test code into the read/write memory, the 2102s, which I had about 1k worth of them, and from there I worked on it, and I got myself enough code in one of these 256-bit codes, EPROMs that I could talk through a radio and pull over information, store it, and pull it over, and then communicate. So that was the start of the PCU.

From there, being an amateur radio operator, I had friends here in town, and they told me-- they had this little Sankyo 400-megahertz radio that came from Japan. I asked my friend, “Well, can you customize one of these radios? Can the company in Japan make one of these things for our frequencies?” and he said, “Well, sure. They probably should be able to do that.” So I talked to Dave about it and we ordered, I

think two or four of them. I forget. We maybe ordered one to start with. We got it in, and it worked so well after Dave went and kludged up the IF, because the IF narrow banded down the signal and this would never let the data go through that we needed, but Dave lined it up, and we put his fast sync modem with it, which he had fully developed by that time. From there, I was able to package it up into this nice little PCU package, stuff the power supply in the back. I wasn't really sure about packaging-- I knew that there was a lot of heat in there at that time, but I thought, well, it got to be small, it'll work, and it did. So I bolted the radio to the top, and coded it up, and we made a programmable control unit (PCU).

Some of the neat things about this unit was that I ran the code in the volatile memories because I wanted to be able to change it. So I talked to Dick, and I said, “Hey, I need to be able to store an image on the Hewlett Packard machine, so I could download the code to run this thing on request,” and so we did that.And we had a downloadable programmable control unit, probably the first one in the world that did that. It was downloadable from the Menehune. I called it Menehune, but it was an ALOHA Systems control unit,

And from there somebody decided, oh, we should build a smart repeater, and Dave and I talked about that, and I said, well it’s got to be full duplex. We got to be able to send and receive both channels at the same time, and I used one computer chip in there, and I had to go and build into the hardware the ability to check for the packet being correct. I decided, well, rather than syncing on the first bit that came in, I was just going to take in 32 bits, and shift them through, and check until I have a correct header, and call it a packet. So that opened up odd, even packet numbers which we never used. But this unit was able to sync on an odd or an even header first bit. It didn't require the first bit. It sunk on the full 32 bits with the correct CRC in it, and that was all done in hardware. I built two of those interfaces, one for incoming channel , one for outgoing channel, and made it play together with one 8080. We put an antenna duplexer in the package, which was not too expensive and fairly small because it was a 400-megahertz duplexer, and it worked very well, and where to go from there? Any questions at this point?

Garner: Sure. I got one for you. So, I was just checking. Your 8080 costing $360 is $2,700 today, inflation adjusted. So one question I had though was did you ever consider using a bit slice like the TI 181?

Harrison: Yes, too much power, too many chips. I did look at a bit slice machine. In fact, I was going to order one in 1975, but the company that made it made it look to good to be true. Maybe I was too naive or whatever. The price looked too good and it was.

Garner: I was thinking you could take the 181 and just build your own little CPU, so to speak, with your own microcode and whatnot.

Harrison: Yes, but as I said, too many chips, too much power.

Garner: Okay, all right.

Harrison: It made a lot more sense to get an 8080 microprocessor and use it.

Garner: How did you handle the CRC calculation? You told me but I can't remember.

Harrison: Okay, a bit at a time. It takes a lot of time. You got to shift each bit in, and XOR it, and move it in and out of a pair of registers.

Garner: It was fast enough you could receive the next packet coming towards you.

Harrison: Well the problem, 9600 baud and the speed of the processor chip at that time allowed me to do just about one parity check while I was DMAing or interrupting and throwing the rest of the packet into memory, so while I was doing the CRC checking, the system was also getting interrupted in the middle of those checks and putting the next byte in, and there was a-- as long as it wasn't-- there was two or three bytes behind it or there was some delay, there was no problem.

And that brings up another issue that there was some sync time when the carrier came up. The radios didn't sync on immediately. So there was at least 10, 15 bits, and I know Dave didn't mention too much about it, but it was a real issue. Because in the repeater, everything is packetized. Everything comes in and goes out. I have to be able to receive on the incoming and the outgoing channels symmetrically, and it didn't matter which channel was which. The code was identical. So it treated the broadcast channel just like the incoming random-access channel.

Garner: On the repeater, did you ever considered listening for carrier, I mean, another packet before sending?

Harrison: I didn’t have the ability to listen. I only had the ability to see the data shifted into the registers and whether it checked, the header checked.

Garner: You didn't have a separate signal from David's circuitry saying carrier is here.

Harrison: No, I did not. I could have, but I did not.

Garner: Okay. Because ironically, I exchanged this story with David. I've talked to Fouad Tobagi, who was the student under Len Kleinrock, and he first thought he heard of the idea of carrier detect from a repeater discussion in Dallas like in 1972, probably with Norm or something like that. So, it must have been a hypothetical thing that Norm was thinking about or something.

Harrison: Well, it was discussed, and just like Norm used to say, well, we use the 4040 to start with. Well, the 4040 is a calculator chip. We never used that.

Garner: The 4004 you mean, yeah.

Harrison: The 4004 or 4040, whatever. They had two different chips that came out. The 4004 was the first one out. It was designed specifically for a calculator and 8008 was the first general purpose chip.

Garner: So do you think you do recall Norm thinking about whether repeaters should do carrier detection?

Harrison: Not really. That discussion came and went, but it kind of went in one ear and out the other.

Garner: Okay, all right. Yeah, it worked fine, so there was really no need to, so I could see how it would be a theoretical question. I mean, Richard was intentionally putting a long delay after every transmitted packet to give you time to resend, so that his next packet wouldn't collide that the thing you're sending.

Harrison: Yeah, actually, I don't know. He didn't really discuss that. But it wasn't necessary because it was full duplex, and I could receive a second packet after the first.

Garner: But the one you're sending might interfere with the next one he's sending. You see? When you're repeating.

Harrison: They're two different frequencies. Oh, that's right. You're right. Yeah. You cannot send two packets back-to-back, because-- well, let me think about that.

Garner: They can be back-to-back, but the fear was that you got one coming in, and you're sending it out, and Menehune is now sending another one, and there could be a Keiki that could receive both your repeater output and Menehune's output, and then they would collide. So I think…

Harrison: That's correct.

Garner: I think Richard, you put a delay in there. Is that right?

Harrison: Yeah.

Garner: I'm asking Richard.

Binder: Yeah, probably. I don't know. That's most likely written up somewhere.

Garner: Yeah, I saw it. Okay. Keep going. Chris.

Harrison: There would be a packet delay. That's correct.

Okay, and then I can kind of go on, I was probably the first to put a microprocessor into a telescope controller. I worked for Institute for Astronomy. They hired me after the ALOHA project. Actually, after the ALOHA project, when the ALOHA project ran down, Norm talked me into going to Hungray-- well, he didn't have to bend my arm too much, but he talked me into going with the United Nations to Hungary to teach them about the PCU and repeater. So I spent a couple of months there in summer of '76, and at that time though, the ALOHA project was winding down, and it was a very interesting trip, a very nice

time, because I was privileged, and I had a passer from the United Nations, and the whole nine yards. So I got to go, and have a good time, and teach microprocessors, and teach radio to the Hungarians.

Garner: How did Norm get so attached to Hungary?

Harrison: I don't know. Go ahead, Frank.

Binder: I think he had a friend that…

Kuo: He and Joan went to Hungary, I think for a whole semester. I'm not sure.

Garner: Invited, lecturer, invited to lecture, yeah.

Kuo: Yeah.

Garner: Okay. Yeah, he also went to Russia too once, right?

Kuo: Well, he never stayed there long. Yeah, in Hungary, he stayed some time.

Garner: Okay. All right, Chris, that sounds really exciting.

Harrison: Okay. Then to go on, about in 1977, Norm invited me to go to Singapore to spread ALOHA ground systems there, and there was a National Conference that he was part of, and with pushing, and promoting, and we tried to stir up some enthusiasm about ALOHA System internationally, but it kind of fizzled out. While there he presented the ALOHA system and what we did in Hawaii, and tried to sell it to various people in Singapore, and also people from Europe there, and others attending from all over the world there, this became an interesting weekend.

And, to go on, and after that, I was going to say, I was invited to work for Institute for Astronomy, and I designed their 88-inch telescope controller, which I used an Intel 8085 in, and I did a lot of innovative things there. The board that controlled the telescope was run by an 8085, and there was an LSI 11, which I talked FORTH Language to do a lot of their telescope work, and I remember controlling the dome, and controlling the moving of the telescope, and all kinds of neat stuff with the 8085 microcomputer.

And shortly after, I was invited to teach at UH. I taught computers and logic design there for ten years, imphesis on microprocessors and so on. After, I went with a startup company, Verifone in Hawaii, one of the few high-tech companies that started-- well maybe one of the only high-tech companies that started up in Hawaii. And going back to previously, you were asking about why high technology, and technology parks, and so on didn't happen in Hawaii. Well it turned out that at that time, Hewlett Packard was interested in coming to Hawaii, but the politicians here, the land was so precious to them and so expensive that they didn't want to give up anything here in town. So they put the technology park out in Wahiawa, and they still call it the technology park, which houses Oceanic and a few construction companies, and so on, and there's really no electronic technology. Well at Verifone, I worked there for a

number of years, and I built and designed a little credit card terminal, which was very commonly used. I didn't build it, but I designed it, the Verifone little square terminal that you ran your card through, which is now obsolete, but it had a Z80 in it. Of course, Zilog, you know all about them. It started with some of the ALOHA people back 50 years.

Garner: Oh, yeah, Charlie Bass started that group. Okay, that's very interesting, Chris. All right. Any last thoughts?

Harrison: Okay, well, let me just show you here. See this little-- I don't know if you can see this.

Garner: No, it's pretty blurred out. Put it by your face, closer to your face. Oh, now we can see it. Yeah. Okay.

Harrison: That is a PCU. It costs $8, built in China. It's got the buffers. It's got the error correction, error detection, radio, everything in it. Only thing it doesn't have is a terminal, and CRT, and the computer which would control it, which attaches to it.

Garner: What network is that for?

Harrison: This is for whatever you want to use it for. It's 2400 megahertz. It is FSK, very similar to what we did with the ALOHA project.

Garner: Cool. Well, they're just 40 years late.

Harrison: Yep, and also for-- I use it-- I don't know if you can see this. This is an SDR receiver, software defined radio, and it covers all broadcasts bands up to 3000 megahertz. It's got an antenna plug one side, which you saw, and it's got a USB connector on the other side. And just make the comment that USB, of course, came from the idea of ALOHA project too, can be traced out from networking, and the protocols work on the USB being able to kind of randomly choose the device, and assign it, and so on. It kind of all comes back to the technology that was first, I might say invented, but figured out by the ALOHA project.

Garner: Yep. Okay, good. Excellent. Okay, Chris. All right. So we've been going for a long time. How about another 15 minutes? Does that seem about okay with people?

Kuo: Yeah.

Garner: Okay. I thought we'd just open it up with some more general questions. You guys have answered most of them already. The only person I haven't heard anything about, maybe you guys could help, was what role Tom Gaarder had in the project.

Kuo: Who?

Garner: Tom Gaarder.

Kuo: Oh, I know. Tom was Norm's student at Stanford, and then he went to Cornell, but it was too cold in Cornell, and Norm invited him to Hawaii. And Tom Gaarder is very-- he doesn't like to publish. But he is one of the most clever people I know. And so in the initial work that the group of us got together, Tom contributed a lot of ideas. But once we had the project going, I don't think Tom involved him very much. Tom Gaarder is also a surfer and the thing that people will remember him is that he never wears shoes.

Garner: Well, that fits for Hawaii.

Binder: Robert, one of the things we haven't talked about at all is the-- one of the things that was fired up around 1972 in the project, which was a significant part of the ALOHA project overall was the satellite work as reflected in the ARPANET satellite system notes, which I particularly got involved in fairly heavily in 1972 as part of the project. But I think that was a very significant effort based upon maybe the first satellite system note that I think Norm wrote up. It sounded to me like it got started by Norm stopping at BBN one day and talking with Dave Walden, and Severo Ornstein, and some other people about, "Hey, why don't we do random accessing on satellite or something and use that on the ARPANET," something along those lines, which he wrote there. In any case, that suddenly appeared as a significant effort which was ongoing. It was all on paper. An ARPANET satellite system was never built. The closest thing to it was the Atlantic packet satellite project, SATNET, which has been featured in the Computer History Museum back in 2007, and that involved-- it was a very fun effort actually, which involved Reservation ALOHA being developed at BBN, and then Larry Roberts developing a more generic satellite reservation system using random access. Both of them used random access, and we…

Garner: You were there at BBN doing this work.

Binder: Yeah, when I left, I'll get to that in a second because it is the fruition and part of some of this stuff. And then in Hawaii, actually based upon initially an idea that Wayne Lichtenberger had worked up, I worked up then in detail and wrote up another third reservation system called Reservation TDMA or whatever I called it. But that was a very significant effort, I thought, from my point of view at least as part of the overall project. It got us very directly involved with a lot of people from Leonard Kleinrock, and his group, and BBN. I don't remember where else, and then it saw fruition in the Atlantic, in SATNET a little bit in that—well

I left the ALOHA project in January of 1975 to go to BBN, who were just firing up the SATNET project, which consisted of taking an ARPANET IMP and adding some code to it to talk to the satellite with what initially was a simple slotted ALOHA protocol. So I'm there, I've come to BBN and picked that up from Randy Rettberg and wrote that module. And so initially, we used simple slotted ALOHA. In the first, let's see, three of them, four of them actually, three or four satellite IMPs, which were not-- after the initial beginning, were not actually a part of the ARPANET, per se. They were embedded within the ARPANET, but routing did not take ARPANET traffic through those links on the SATNET channel. So that was the extension of the ALOHA channel, if you will, two satellites, and then we went on to then get-- it ultimately ended up as a fairly sophisticated reservation scheme based mostly on Larry Robert's initial…

Garner: Did your proposal get implemented?

Binder: No. I was of course, being the guy that was writing the software, was all set to put it in there, but in fact, Irwin Jacobs was leading the multi-contractor effort at that time. It was Bob Kahn had set it all up and funded it. But he turned the technical leadership over to Irwin, and Linkabit, who was his company at the time, had the charter to really work up the final protocol that ended up there. It was somewhat of a group effort, but it ended up being CPODA and FPODA. CPODA being Contention-based, Priority Oriented Demand Assignment, a very generalized reservation scheme using slotted ALOHA for the reservations, the Larry Robert's scheme.

Garner: Right. Well, yeah, I definitely-- by the way, I was able, because Kleinrock donated all the ARPA system satellite notes to UCLA, as you saw, I now got copies of all of them, including the ones you did. I definitely saw it as an extension of the ALOHA System project. And I mean, you don't have to worry about hidden terminals if you put the Menehune up into the sky, and everything goes up, gets broadcast to everything on the ground, so you get around a lot of problems, and you don't need repeaters. It's like a blessing, a great blessing.

Binder: Well and the offshoot commercially, in a few years from that, was VSATs, VSAT small aperture satellite networks.

Garner: But what I saw happen I guess, was that the person who was really allowing you to go ahead, which was Larry, he left then, and went to go to that startup, to that company, right, and then…

Binder: The X.25 stuff, yeah.

Garner: Yeah, and then what happened was Bob Kahn got all excited about packet radio, which went off to become a 10-year project that had just massive complications and challenges.

Binder: Yeah. There was one-- by the way, if I take another couple of minutes here. There is an interesting little thing along the way here. Just after we-- in 1975 had put in the slotted ALOHA and the satellite IMPs, and we installed one at Eaton, West Virginia, and then another one over in the UK, and we're bringing them up and having them talk to each other, still as part of the ARPANET. And in fact in that very first-- when we first brought them up, we didn't have any restrictions or controls. When we opened up the channel, we brought them up one evening and had them start talking to each other over the satellite channel, as part of the overall ARPANET, but using ALOHA.

And so as soon as the routing algorithm of the ARPANET saw that via the seldomly sent control packets said that, hey, I've got a path here, and it's pretty good, I've got 50 kilobits roughly of traffic path here, as opposed to the 9.6 that was otherwise in existence to connect to the UK. So myself and another person was sitting in the ARPANET control center. We had a little board of lights up on the wall that was blinking, and so forth, and showing status of each of the ARPANET IMPs out there at the time. And as soon as we brought it up, it was two satellite terminals, and they started passing traffic, all hell broke loose in the ARPANET, at least in the information coming back to the control center. Each IMP would send some information periodically which would cause the lights to say, hey, everything's okay here, and this IMP is all okay and everything. And suddenly, it was this wave of lights going on and off, and the fellow who ran

the control center at that time was helpless to go in. He couldn't reach our satellite IMPs to turn them off, and then of course, once routing decided, hey, well, this is not working very well, so I'm not going to send traffic that way, and then it would settle down again and be okay, and then immediately get back into that state, and so it was oscillating like this, until finally, he was able to get in there and shut it off. So the bottom line of this, this was the very first experiment that demonstrated that we needed an internet because trying to run this within the ARPANET itself with ALOHA protocols was a disaster, of course. Anyway, that's my little story.

Garner: Well, yeah, that's a fascinating story. There were certainly no good flow control mechanisms in the first ARPANET. So I could see how if you were overloading the system, it would just get an odd linear.

Binder: Well, routing wasn't prepared. Routing had certain exceptions about lines, and it wasn't prepared for ALOHA.

Garner: Okay, that's a fun story. All right, so I was going to just go through. Yeah, thank you for bringing up-- I forgot to ask about the ARPA satellite system. That's really good because that's kind of what it evolved into. So a few other questions I had for all of you guys was “How extensive was the ALOHA system?” I think there was a terminal in Norm’s office. There was some in the lab. There was a community college nearby, I think that you guys linked to, but that was about it, right?

Wax: Yeah. We set up a terminal over at the Winward Oahu Community College.

Garner: Okay. You said they really liked it. They didn't want to give it up.

Wax: Yeah, they liked it. We went to the repeater on that one, actually. Alan and I worked on that. We used a Yagi antenna, directional antenna pointed at the repeater.

Garner: Okay. Were there any other installations, any other cities or islands, Maui or…

Wax: Well, we took one or two of the TCUs around to demo. Remember, Alan, didn’t we take a TCU down into the Princess Kaiulani Hotel one time? There was some conference or something there and we set it up on a table in there. Do you remember that?

Okinaka: Vaguely.

Wax: Yeah.

Okinaka: I think I remember trying to-- almost like we were trying to market this thing.

Wax: Yeah, I think we were trying to peddle this thing and it was interesting because you had no direct line of sight inside the building. But you had this standing wave pattern in there, and all you had to do is move the TCU around a little bit, and you had a solid link. You’d just have to hit a hotspot. And we had it set up on a table right inside this big hall or whatever it was, and demonstrating how we could

communicate back to the 360 with it. And then the only other one I think that I know of was the one over at the community college, and then a brief test up to Haleakala.

Garner: We're not counting that. Okay, so there were no other permanent installations. How about on the campus itself, besides the Norm's office and your lab?

Wax: Well yeah. We had a few set up there in Holmes Hall, as I remember.

Garner: Okay. Any memories from anybody? Anybody else on where they were distributed.

Binder: I think I had one from early on in my office down in whatever that section of the campus was, over at those bungalows near the…

Wax: Oh, over there, yeah.

Binder: I can't remember for sure, but I think I had one. Alan, do you remember, or Dave, whether..?

Wax: Did we have a TCU back then? We're talking back before we moved to Holmes Hall.

Binder: Well, I never moved to Holmes Hall. I stayed…

Wax: Oh, that's right.

Binder: …for the duration over in that bungalow. That's where the Lockheed SUE was, and that's where your radio you were talking about for that was.

Wax: Yeah.

Binder: I think that radio, by the way, was because one of the original motivations for the Lockheed SUE was to load up the channel it seems like. I'm not sure we ever actually ended up doing that. We did a lot of simulations with it. But I don't remember if we actually put stuff out on the channel from it or not. That was all in that-- one of those bungalow buildings over there.

Wax: So you had one of the TCUs over there then.

Binder: I think so. Pretty sure I did.

Wax: Yeah, you probably did.

Garner: Then eventually, the TCUs were replaced by the PCUs.

Wax: No. I don't think there was more than one PCU ever built, was there, Chris?

Harrison: There were two built.

Wax: Two built, okay.

Harrison: Yes, and I occasionally would have the opportunity to take one home, and use it from my home, and one of the interesting things about the whole project there is that to get into that IBM machine, you had a modem, which was a Teletype rate, and you had to have a Teletype, a big clunky machine. CRTs were like two grand or more at that time.

Garner: That would be 20 grand today.

Harrison: Yep, and going back, there was only one place that you could really get high-speed data to and from, and that was the IBM machine, and that was sought after. I mean, people really wanted to get into the timeshare option, and do their programming, and store their files in there, and doing it via landline, it's just 300 baud. 1200 baud modems, you have to remember, didn't really come out until '76, '77. That quadrature modulation was-- it was late and it was expensive. Dave, you probably recall a lot of that.

Garner: Yeah. So it's too bad that you guys couldn't have gotten a giant grant because you would have been loved by all the students everywhere and all the professors.

Wax: I remember when we did that setup over at Leeward Community College. We had a CRT over there, didn't we, CRT terminal?

Harrison: Yes. I'm sure you did.

Wax: Yeah, and I remember these kids had been working from there. They'd been working into the 360 via phone line before that and just hating it. It was just chunka-chunka-chunk, and we set that thing up, and these guys couldn't believe it. They just-- here's the CRT, and they'd put a query into the computer, and the whole raster just, boop, up at once, and they just, "What!?" and that was just a 9600 baud.

Garner: Yeah, that was a big step back then. I remember. All right, so my next question is…

Wax: Anyway, the point is, they didn't want to give it up.

Garner: They didn't want to give it up. Yep. Okay. So my next question is there was this TCU failure light whenever the three, three transmissions would fail, or maybe there was too much noise. How often did that come on and the system would lock at that point? Was that a common phenomenon early on, or just really rare?

Okinaka: We never really kept track of it. I mean, I saw it go off and on, but I don't think we tracked it through.

Garner: Okay. It wasn't common.

Okinaka: No.

Garner: Maybe it was due to like radio car noise or something, interfering with transmissions or?

Harrison: Well most likely, it was due to your location, because the buildings we were in were steel reinforced, and as Dave pointed out earlier, you move to a sweet spot, and it worked well. And I remember taking that PCU and moving it around, and you could hear when the radio would go, beep, beep, beep, retransmit, and you'd have to, oh, okay, it's not receiving, we'll move it a little bit, and it would start working.

Garner: Yep, sounds real. Okay and then you guys ever-- I know I've asked you before, and I'm still working with Bob in trying to figure it out. But do you remember anything about Metcalfe's visits at all or him himself?

Binder: Bob.

Garner: Yeah, you were the person who hosted him first, Richard.

Binder: Well yeah, I had this-- I think it was in 1972, where I had a call to my office one day out of the blue from Bob, who said he wanted to come out to Hawaii and learn about what we were doing, and he did, proceeded to come out and spend some time. I think he was only there for a day or two.

Garner: Yeah. The impression I got, I need to ask him, is he wrote this paper on controlling the ALOHA, the Pure ALOHA, right, which was the idea that a station would not transmit-- if you had Q stations waiting to transmit, the probability of anyone coming on was one over Q. So that would then result in a nice-- instead of getting locked up into everyone screaming at each other, at least it would plateau out. And I'm not sure if he wrote that analysis while he was there, or he did it first, and came out and wanted to run it by you guys.

Binder: He did make a presentation, I think that afternoon to Norm, and me, and probably one or two other people who were there, on something, and showed some <inaudible 02:44:32> and things, and that's my memory of it.

Garner: I'll bet you it was this. I'll bet you he did the math. It's something you could do in a couple of days too, right, and he wanted to see what you guys thought about it is, I'm guessing, and apparently, you guys gave him positive feedback, and I mean later, Norm in his oral history said he thought Metcalfe had "student-itis," meaning he needed to-- well, he needed to get his PhD done.

Binder: Well, yeah.

Harrison: I can recall one time where a group came out. I don't know from where, but they had a 6800 machine, and they were trying to interface it into the Menehune, and they spent two or three days trying to get that thing to work, and I remember going over and talking to them, and saying, “Hey, can I help you with something? I can look at the code or whatever.”

Garner: This has got to do with Bob Metcalfe.

Harrison: I don't know if it’s Bob Metcalfe.

Garner: Oh no, this might not have been Metcalfe.

Harrison: It was somebody out of the SRI or someplace.

Garner: Yeah, that could be. Any other memories on Bob Metcalfe though?

Binder: One of the things I think that's significant is that Norm got a hold of somehow, and I don't know if he actually eventually found its way maybe from Bob into an ARPANET satellite note or not, but was the memo, and Norm references it in that “Surfing with ALOHA” paper or whatever it was [The AlohaNet -- Surfing for Wireless Data, Ref3], a memo that Metcalfe wrote, and I believe it's dated May of 1973. It was an internal memo report about changing the name from “ALTO ALOHA,” or what you guys were building, or whoever was building then to ETHER [Network], and using the word-- the name of ETHER instead of ALOHA because of this, that, and the other thing, and so forth. So and then he went on to-- it's actually a long memo. There’s some other stuff in there too. That might actually be in one of the ARPANET satellite notes.

Garner: Richard, that memo that Bob wrote inside Xerox, we all have copies of it. It was May [22, 1973]. You’re right, May. But you're saying that somehow Norm saw that memo.

Binder: Yeah, I guess he shared it with Norm because Norm referenced it in that 80 something paper that he did for the IEEE publication on “Surfing for Wireless Data”[Ref3]or whatever it was.

Garner: Okay yeah, it's very possible. I mean PARC was a pretty open place. They weren't confidential memos at that time.

Binder: Norm, of course, grabbed onto it because it started off calling it the Alto ALOHA.

Garner: That's correct. It was Bob originally internally called it the ALOHA Alto or Alto ALOHA Network. It turns out, I actually have copies. Someone there at PARC saved all of his memos, and I actually have two memos before that famous made. By the way, he wants to celebrate the 50th anniversary of Ethernet this coming May 22, so you guys are all invited. Marc, do you know when the date is yet, Marc Weber?

Weber: It’s the actual date, so it’s a Monday, I believe.

Garner: Do we have a date though for the CHM celebration?

Weber: Yeah, Bob really wanted to do it on the date, and we said fine. I mean Monday is often not the very best day, but we are doing it.

Garner: Yeah, May 22 is Monday. Yep. Okay. Yeah, it turns out that that's when he-- of course, his design wasn't complete then. He didn't have the exponential backoff. He didn't even know how he was going to control the network. The memo is just very stake-in-the-ground-like thing, and actually, the first ethernet, David Boggs would tell you if he was here, wasn't really working until November of that year [1973]. So but anyways, Bob really latches on to that memo. So it's interesting that he showed it to Norm at some point.

Binder: I don't know how Norm got a hold of it, but he did.

Garner: Well, Bob has always been upfront, and I think Norm was always happy about that, that he would attribute-- So yeah, the next time that Bob came was in January of '73 for the sixth HICSS conference because that's when he presented his controlled ALOHA paper. He added that paper to his dissertation to get his PhD. And does anybody remember him giving the talk? Frank, you were the-- well, I think Norm was the session chair. Frank, I don't know. You may not have been there. Were you there?

Binder: I was.

Garner: You were there, Richard, probably.

Binder: Yeah, no, I think Frank was the chair of that.

Garner: Okay. Do you remember him giving his talk, Frank, at the HICSS. Oops. I put Frank on mute. I've got to unmute him. Yeah, unmute yourself, Frank. There we go. Oh, Frank, you're on mute.

Binder: Frank, you're muted.

Wax: You've got a button on the left side, Frank, at the bottom. There you go.

Kuo: Now I'm okay. No, I don't remember that talk. I could just remember he and his wife came, and Jean gave her a flower, and she asked Jean, "Do you speak English?"

Wax: [Laughter]

Garner: Yeah. So from what we can tell, Bob was only there for these few days in September or October of '72, the January '73 conference, and then he came for-- I know from his records at PARC that he came October '74 for a one-month vacation in both Maui and Oahu and he worked-- he met with you, Richard, during that time.

Binder: No. He was interacting with a lot of people on the project during that visit because that's when we'd bring together the retrospect paper, that looked back on the whole project, and said what we would do differently and all of that. That was in '74, and he, I remember was kibitzing that, providing some inputs to it in terms of observations, and well, you ought to do this, and that, and the other thing in the paper. And also I noticed that around that same time and later '74, apparently I wrote up my round-robin satellite reservation scheme for publication and presentation in '75 at ICC, and I acknowledge Bob for his reviewing of the paper or something before, and helpful comments, and all of that. So, he was around doing stuff at that time.

Garner: Yeah, that was about when he left Xerox, by the way. He left Xerox PARC in about '75 and went to…[Transaction Technology, Los Angeles].

Kuo: I have to leave pretty soon.

Garner: Okay, we're about done. I think that was almost my last question. My second to last question was how do you guys feel about the 360 being called Kahuna, the IMP being called Menehune, and the user terminals called Keikis? Was that, a student did that? Were you guys okay with that?

Binder: Well, throw my two cents worth in it. I think Menehune is an apt name, given that there's a lot of similarity in the overall functionality or the role it plays of the Menehune to the ARPANET IMP, which they were both coming up, or well, the IMP was already up, but so I think it-- and given my understanding of what Menehune is, my interpretation of it, that it's kind of appropriate. I don't think any of us ever used Keiki beyond using it with whoever defined it, and I was given those names to use for that original 1969 paper report. I don't know that we ever used them after that. We certainly didn't say the words much at all. And Kahuna was again, kind of a nice name for the role of the 360. But I don't think we ever used that, called it that. Menehune did stick ...

Kuo: We only used Menehune a lot.

Binder: Yeah, that stuck.

Kuo: Because it was in Norm's papers.

Garner: Okay, and Alan, do you have any memories of these names?

Okinaka: Yeah, of course, if you ask a Native Hawaiian, they'd probably get very offended. But I didn't see the names apply to the function in the network. I know looking at IMP, you're taking a physical dimension to say Menehune because Menehunes are small people. But other than that, the meaning, or the people, that Menehune was not properly applied, I think. In the Hawaiian culture, there's about 15 different Kahuna, and they're specialists in different aspects of their communities, the culture, the belief, the history, and everything like that. And so there is not just one, like a chief of a place. It's not like that. It's a Kahuna were specialists in different areas, and of course, Keiki, you keep on mispronouncing Keiki, so you need to know it's Keiki, not keki, but it's a child. And I didn't see the terminals of being children, but

hierarchically, maybe. That's the whole idea was to have the top thing, and the middle thing, and the bottom things.

Garner: Yeah. I think in my book, I'll probably not show-- copy the illustration that shows that because since you guys didn't really use it, there's no reason to dwell on it.

Kuo: I've got to go. All right?

Garner: Okay. Frank, any last thoughts?

Kuo: All right. This is the last message.

Garner: Last message. Go, Frank. What do you want to say?

Kuo: Goodbye. Thank you very much for this wonderful meeting. I think you really did a great job. Thank you.

Garner: Well, thank you, Frank, and thank you for your suggestion of having it.

Wax: Thank you for giving us the opportunity.

Garner: Yeah, they're all thanking you, Frank.

Harrison: Thank you, Frank.

Kuo: Aloha.

Weber: Thank you to all of you for this wireless world.

Okinaka: I hope I get to play poker with you.

Kuo: Alright..

Garner: All right. Any last words from anybody else?

Weber: I'll send an email with some follow up things I'd like to collect and things like that. Thank you so much.

Garner: Okay. David, do you have any last words?

Wax: No. It's just a great meeting is my last words. I really enjoyed seeing everybody again. It's been a few years. We had a great team. We did a lot. Yeah. And we had fun doing it.

Harrison: I have to agree with David.

Binder: It's been a fun get together.

Garner: Yeah. I've enjoyed it. Alan, any last words?

Okinaka: Yeah, I just wanted to add that the timing was good when I left ALOHA Systems to go to GTO and Intel because that's exactly when they wanted to start their data communications network. Up to then, it's just been telephony, and so it worked out quite well. But the problem they had was they were debating between circuit switching and packet switching, and in telephony circuit [switching] is kind of golden. Right?

Wax: You bet.

Okinaka: Packet switching was something they kind of-- their eyes glazed over when you talk about it.

Wax: Yeah.

Okinaka: I think the significant contribution that I made holding my buck was to get away from circuit switching and move over to packet switching. So we worked with Bolt Beranek and Newman (BBN) to bring in packet switching system, and that became the way that we provided data communication services. I mean, we still had-- synchronous lines for a lot of the networks that the banks and everybody had, but for timesharing purposes, packet switching was the service that was provided.

Garner: Okay. All right. Well, we've gone…

Weber: Sorry. I did think of something I'd forgotten. You know Larry Roberts. He did a paper on that handheld terminal, which he said was partly inspired by ALOHAnet, of course. Do you any of you remember that?

Garner: Well, it was part of the packet radio project. That was his goal for what he wanted. It was going to be a handheld thing with your fingers like this, and you would actually enter ASCII letters, or whatever binary pattern with your fingers, and it'd be used by people in the field.

Weber: But did that trickle back at all to ALOHAnet?

Garner: No. It became packet-- It was a vision for the future, like for packet radio. But the reality was, to produce the radio, you needed something about this big, a footlong and a half-feet wide. So it was just a dream of Larry's part.

Weber: Totally. Right. I'm asking you about the dreams. Also, Norm was very proud of that phone with the big antenna picture. I guess what I'm saying is, was Norm and Larry both talked in their oral histories

quite a bit about that as being a vision of the future. But was that-- were you guys aware of that? Was it informing any of what you were doing?

Harrison: I can speak up and say that I was very aware of it, and Norm and I had a few talks, though not extensively that, hey, I want a handheld terminal. I want to be able to hold it in my hand, and it is possible now, but the technology just wasn't there.

Weber: Oh, yeah.

Harrison: It is definitely possible now and it's done now. In fact, we have now, if you're familiar with what's going on, the latest Apple product actually has satellite communication capability in a handheld phone. So, it's come about now, but we were 30 years ahead of our time. Or behind our time, I mean.

Wax: Oh, we didn't have the technology back then to implement that stuff. I remember Norm mentioning to me that what was coming was cellular radio, and he encouraged me to get involved in it, and stupid me, I didn't. I wish I had, but he was-- Norm's thinking was way ahead of everybody's. He was already predicting cellular radio was going to be a big deal.

Garner: Interesting. All right. Any other questions, Marc?

Weber: No, that's good.

Garner: Okay, all right. So anyways, I wanted to thank all you guys for this great session. Three hours, I know that's a long time. Realize that the work you did, there's a direct path between your work and today's networks. It went to Ethernet and then it went to various forms of Ethernet. Then it went to WiFi, and then metro Ethernet. Now the telcos do Ethernet. So there's a direct line path where each step is compatible with the previous step. So you guys helped change the way the world works, actually, and so thank you very much for that.

Binder: We'll look for our checks.

Garner: What's that?

Binder: We'll look for our compensation checks.

Garner: Oh, yeah. There are a lot of zeros in it.

Harrison: Can I say something real quick? I am thinking that the future is even going to go further now that we have the ability to actually do A-to-D and D-to-A at radio frequencies up to 600 megahertz or higher. We can create, with a computer, a radio image out there, and we can do spread, narrow, whatever you want on top of radio, and put it out there without a modem, without anything, you just put the pattern out there, and it gets transmitted, and you pick it up on the other side, and with some diversity where you maybe pick a pattern that exists and compare it to the incoming pattern and get the

information out of there. You should be able to transfer broadband, multiple copies of it, having multiple transmitters see them all at the same time with the receiver, pull it in with the-- in an A-to-D, and with the computing power that we got now, pull it apart, and we'll go from there, and I think that's the next thing.

Wax: Aren't we basically doing that now?

Garner: Well, we'll be awash with so much information, we'll need AI to interpret it for us.

Harrison: Yeah, well, radio amateurs are doing some of that with the modern SDR transmitter/receiver units which have been out since about 2010. I want to say, progress has been taking place from 2018, 2019, and I've got a pair of these modules here; -- we're seeing China knock off this stuff off designed in Europe & America. And with these little computers like the Raspberry Pi.[Putting an image on the screen]. You probably can't see it, but you've seen them everywhere, and they're cheap, and there's just a whole lot you can do with these. The technology is going to turn over again, and we're going to see another band of changes, and the next step forward is coming from where we are now.

Garner: Okay. On that note, why don't we-- that's a good way to talk about the future to end this discussion about the past. So anyways, congratulations. Great work. I'm glad it's still ongoing, and I look forward to more email exchanges with everybody, and we'll go ahead and stop this session now if that's okay with everybody.

END OF THE INTERVIEW

POSTSCRIPT (5/27/2023):

Garner: One topic we neglected to discuss during the panel session was a proposal that David Wax made in 1971 to explore a carrier detection scheme in the ALOHA System. In Fouad Tobagi and Len Kleinrock's December 1975 paper "Packet Switching in Radio Channels: Part I — Carrier Sense Multiple-Access Modes and Their Throughput-Delay Characteristics," in the *IEEE Transactions on Communications,* a footnote states:

"Sensing carrier prior to transmission is a well-known concept in use for (voice) aircraft communication. In the context of packet radio channels, it was originally suggested by D. Wax of the University of Hawaii in an internal memorandum dated Mar. 4, 1971."

The reference to David's proposal raises the question of how would carrier detection have been implemented in the dual-channel ALOHA System? Given that it employed two separate frequency channels — a random-access broadcast channel from the terminal TCUs to the Menehune and a round-robin always-on channel from Menehune to all the terminals — for a terminal to defer transmission if the channel was occupied would require another receiver tuned to the frequency of its transmitter, a steep additional cost.

Here is David Wax's explanation and recollections about his March 1971 carrier sense proposal in the ALOHA System, according to a May 2023 email exchange:

David: When I proposed the concept to Norm, I had no idea how to implement it. I knew that my demodulator at the Menehune frontend could reliably detect the subcarrier signal when a packet arrives within the first ten-bit periods. But I did not have a specific proposal on how to implement it. I would have worked with Richard Binder in coming up with a practical scheme. For instance, the Menehune could immediately, upon notification, broadcast a control packet to all the terminals. But it was moot since Norm decided not to go forward with it.

These carrier sense ideas were not really CSMA, but more of a centrally controlled user transmission system. It was just an idea I kicked out. I had no idea it was going to create so much attention. Norm decided to give me credit for it, which I greatly appreciate. But, to me, it's an obvious concept because it is performed every day in push-to-talk radio communications. I fear I'm like so many engineers, I was trying to make order out of disorder. Although Norm appreciated my proposal, he did not want to complicate the Aloha design.

I feel Norm viewed my proposal as something we should explore in the future, after we got experience with the pure Aloha random access channel. He agreed that it would improve efficiency of the channel. We had so few users (TCUs) on the channel, that there was no need to improve efficiency, and any improvement would not be detectable. It would have been fun to implement carrier sense, but our main goal was to demonstrate the viability of a random-access channel to multiplex multiple users of a single channel into a single input of a large computer.

REFERENCES:

[Ref1] William C. Lynch, "Reliable Full-Duplex File Transmission over Half-Duplex Telephone Lines," Communications of the ACM, v.11, No. 6, June,1968.

[Ref2] Shu Lin, Introduction to Error-Correction Codes, Prentice Hall, 1970.

[Ref3] Norm Abramson, "The AlohaNet -- Surfing for Wireless Data," IEEE Communications Magazine, Dec, 2009.