The Future Depends on Innovation

An interview with

Irwin M. Jacobs

Cofounder, chairman, and CEO of Qualcomm

Ken Wagner, *IEEE Design & Test*'s interviews editor, spoke with Qualcomm's Irwin M. Jacobs during an in-depth interview discussion. *D&T* follows Jacobs' extraordinary career, from the radio location of America's trucks and automating Wal-Mart communications to creating and licensing what looks set to become the dominant cellular technology worldwide from Qualcomm.

D&T: Tell us about the role of your parents and mentors while you were growing up.

Jacobs: I grew up and attended school in New Bedford, Massachusetts. I had two very good teachers in high school—one in math, one in chemistry—who had quite an influence on my future. My guidance counselor advised me that there was no future in science or technology, even though my interest was in math and science. When the guidance counselor learned that my folks owned and operated a restaurant, he suggested I attend the hotel school at Cornell University. So I started out in the hotel school, without realizing it would later be an advantage—one year of accounting and a half-year of business law. But I quickly found that my interest was elsewhere.

I went back and spoke to my high school chemistry and math teachers during a holiday break and decided on engineering. My parents supported me, even though it meant a longer term in college. Luckily, I obtained some scholarships as I went along. With that experience in mind, we have made Qualcomm a great supporter of scholarships and fellowships for students.

D&T: Did you earn both your bachelor's and graduate degrees at Cornell?

Jacobs: I transferred into the electrical engineering co-op program at Cornell [after attending hotel school for three terms], and spent every other quarter at Cornell Aeronautical Lab in Buffalo, New York. Near graduation, one of the engineers I worked with at Cornell Aero Lab said, "You know, you really should apply for graduate school." Up to that point, I hadn't really thought about it—I'd already met and married my wife, Joan, who had graduated from a four-year program; I ended up with a six-year program.

In any case, I thought about graduate school, discussed it with my wife, my parents, and applied to only one school, MIT [Massachusetts Institute of Technology]. I also applied for one fellowship—a General Electric National Fellowship. Luckily, they both came through, so I went to MIT and earned both a master's and a doctorate in electrical engineering in three years.

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Originally, I considered specializing in electromagnetic theory, because I was very excited by some of the work at Cornell and also because Professor Henry Booker was one of my instructors. But when I got to MIT for graduate school, Claude Shannon was there, as was Robert Fano and Peter Elias—studying information theory—and I became intrigued.

I also was lucky enough to take a course from Norbert Wiener. A group of graduate students would go to the lecture but couldn't make any sense out of it. At the end of each lecture, seven of us would meet, try to figure it out, and make notes. About halfway through the term, Professor Wiener found out, stopped in at our gathering, and said perhaps we should write a book. And so we eventually did put those notes together as a book. When the book did come out—*Nonlinear Problems in Random Theory*—it was an interesting experience, and got me more interested in probability theory and information theory.

D&T: Who became your adviser for your doctoral degree?

Jacobs: There were two. Yuk-Wing Lee, who was in communication theory and headed up a group in the RLE [Research Laboratory of Electronics] at MIT, and Ed Arthurs, a young assistant professor very interested in aspects of information theory and network theory.

My thesis had to do with the reliability of communication networks, combining network theory, combinatorial analysis, and probability and information theory.

D&T: Did you go immediately into teaching, or was there a hiatus?

Jacobs: About the same time that I completed my master's degree, our first child was born, so I was in a rush to finish both the master's and doctorate degrees. I thought of taking a position with a company but was offered an assistant professorship at MIT, so I decided to stay on and remained there for seven years.

One of the many positive aspects was that Jack Wozencraft was also on the faculty. We began talking about trying to put together a senior-level course on communication theory combined with information theory. Bob Fano and Wilbur Davenport were also interested, but rather than trying to do it theoretically, I wanted to have more applied material. Jack and I agreed, and so we ended up being the coauthors on the book, *Principles of Communication Engineering*, which came out in 1965.

D&T: That opened the door to your future …

Jacobs: Very much so. Even today, I'll often run into someone who still has the book, or took a course with the book. The fact that it's still used, that others have found it useful, has been very positive and of course opened a number of doors.

D&T: It must be very satisfying to have a classic text that survived and that remains useful today. The fundamentals of physics don't change, but there are very few authors who can say that about their book.

Jacobs: Right. It was focused on digital communications, and at the time, people were focused on analog—how to improve analog, how to make FM better, and so on—yet we were talking about digital communications, and of course that's the direction the world is now going.

D&T: As a next step, what started to make you think about moving to the West Coast?

Jacobs: I requested a leave of absence; I had been offered a resident research fellowship for nine months at JPL [Jet Propulsion Laboratory] in California. We always wanted to visit California, and this sounded like a good opportunity. As an assistant professor, you don't have much money so we bought an old Ford Econoline van. By that point we had three children, so we built a platform so that they could sleep, and we camped across country over a three-week trip to California. We spent nine months there.

Just after getting back to Boston, I had a call from Henry Booker, the professor at Cornell who had taught me electromagnetic theory. He said that he was going to be starting an electrical engineering department at a new school—the University of California at San Diego—and asked if I would come out and join him and help get that program moving.

That sounded like an interesting opportunity, but with family, friends, and career all on the East Coast we turned it down.

For the next two days, we were really unhappy with that decision. The second day, I left MIT in a heavy rainstorm, took a subway to Harvard Square, waited in the rain for a chance to get on about the fourth bus or so out to Arlington, where we lived. Mid-ride, everybody's wool clothing began to dry out—there was this terrible odor in the bus. When I arrived home, I said, "What are we really doing here?" My wife, Joan, said, "I have some

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information about a house"—we'd been looking around for one—so she read me the description and I said, "That sounds great. Where is it?" She said "La Jolla." So we called Henry Booker and said if the position's still open, we're coming.

D&T: So ultimately it was the weather that convinced you.

Jacobs: The weather obviously played a part. But it was really the chance to teach in a brand-new public university with a different set of students—and being able to frame a curriculum—which all sounded exciting, as did the opportunity to live in California. We also considered that if we ever wanted to move there, doing it sooner rather than later (given that real estate just kept going up) would probably be a good idea. It turned out much better than I had anticipated.

I taught at UCSD for six years, and it was a very exciting period. There were many requests for consulting, so I consulted one day a week. Consulting keeps you aware of what's happening in the industry; you can frame research problems in a way that can have some practical utilization. But there were many more requests than I could keep up with. One day I was flying down from NASA Ames—with Len Kleinrock and Andy Viterbi, who were both teaching at UCLA at the time—and mentioned that there was more consulting than I could handle. They said, let's set up a company and share the consulting. I said, "Fine, as long as I don't have to manage that company." That was the birth of the first company, Linkabit.

We started as a consulting company, got a number of contracts, and hired a few full-time people. I realized that I better take one year off and get this whole thing organized, so in 1971 I took a leave of absence from UCSD to help organize the company. During that year, I found it to be lots of fun, so I decided it was time to change careers, and I switched to business.

Linkabit grew very well; we developed a whole set of products. For the first 10 years we were heavily involved with government work—for example, in extending the Arpanet to Europe. I led a project that involved a number of different communications technologies. We developed a satellite terminal that probably was the first practical use of a reduced-instruction-set computer, even though I'm not sure if RISC was even named at the time.

D&T: Did you have a vision for the company, or were you more reactive, looking at what the government needed?

Jacobs: We'd look to see what might be needed, where we could come up with a new idea, and try to be innovative—that is, we looked for a place where we could make a significant difference. If we could develop the product quickly enough and rush it into the market, and if it were successful, hopefully then there would be a larger business and that would generate funds that we could use to generate the next products.

We did a number of products for the government—defense department, NASA, and DARPA—then with that background we began to develop some commercial products. We became involved with very-small-aperture earth terminals, VSATs. Schlumberger had a request for proposals to develop a small terminal to go on oil exploration trucks and bring back data as it was gathered, and which let a customer decide whether to continue drilling. We developed a terminal for that, then realized we could make it even smaller and make it more commercial if the FCC would let us install these terminals without needing a separate license for each location. The FCC eventually agreed to that, so we came out with the first of the KU-band VSATs with 7-Eleven stores and Wal-Mart as the initial customers, giving us a very strong start.

We had a bid request from HBO to develop a scrambling system, which we later called VideoCipher, to scramble television signals being transmittted from satellite to cable head. Although others had more experience, we won the contract, but just before we began to manufacture and sell these units for use with cable systems, HBO realized that Congress wasn't going to allow that because of a group of backyard dish owners, who had been receiving the television channel [for free] over the years. They said they were willing to pay to receive it, but they had to have a way of doing that, which meant that the scrambler had to be usable in the home, so it had to be much lower cost and less complex.

We decided that if we could quickly develop three chips, one of which would be the encryption/decryption chip, then we could solve this problem and go ahead with the HBO contract.

So we developed three commercial chips using software that we had patched together from internal and a number of external sources, since commercial design packages were not yet available. Luckily, they all worked on the first pass, and, in a sense, that launched our understanding of the chip business and one that's carried through, of course, into Qualcomm as well.

We sold Linkabit in 1980. There, we developed, besides the VideoCipher and the VSAT, the first commercial TDMA [time division multiple access] telephone plus a number of military products.

I left Linkabit on April Fool's Day of 1985, retired for three months, and then decided that wasn't much fun, so I started Qualcomm with six others who had worked with me at Linkabit.

D&T: At Linkabit, how did you decide on which team member would do what?

Jacobs: We were very opportunistic, starting with consulting projects and using our academic and theoretic backgrounds. With one of our early full-time engineers, Klein Gilhousen, I became very involved with developing products, first for the military and then commercial. Again, the criterion for a project was whether it was innovative and could lead to interesting production if successful. Len Kleinrock was only with us for a short time, and he decided to go into something different. Andy Viterbi ultimately retired from UCLA, moved to San Diego, and became part of the company.

By the way, Linkabit grew about 40% to 50% per year, so it was on a strong growth path. Because we started with defense business, we could use progress payments to generate a cash flow; therefore, we didn't have to go out and raise money. Actually, neither Linkabit nor Qualcomm made use of venture capital money. With Linkabit, it just didn't exist, and with Qualcomm, we managed without.

D&T: In your current role, which do you enjoy more, the technical or business aspects?

Jacobs: The technical aspect was always interesting. It's helpful to have someone with a technical or engineering background be the CEO in a high-tech company, because you can understand what can be done. You can evaluate ideas, get a feeling for whether you can be successful in a reasonable time, and whether there might be a product. I interact quite often with the engineers, although much time is also spent on business. Sometimes I think it's similar to university teaching: Part of the time, you're doing coursework and advising graduate students. When graduate students come up with ideas, they'll discuss the ideas, you perhaps give them a little redirection, and off they go. In business the end result is different. You're trying to get a product, as opposed to a thesis, but that kind of interaction is always positive. I try to divide my time between the technical and the marketing aspects.

D&T: Let's go back to the formation of Qualcomm. How was it born, and how did it evolve?

Jacobs: One of the exciting things about business is being able to come up with ideas, seeing them developed and become products that are useful to people. So, during this period when I just retired—although I was doing a little consulting and so forth—there wasn't quite the same excitement. Additionally, several people from Linkabit said, Let's start another company.

During a family trip to Europe, I finally made the decision to give this new company a try. We started without a product. I thought it would develop somewhat along the lines of Linkabit, where we did government work for many years, then became well enough known to win commercial work. In fact, the commercial work began early and has been our prime thrust, although we continue to value work for the government, largely adapting commercial products to government use.

We started Qualcomm with the idea that we would try to be innovative—look for an idea that could make a significant difference, but we didn't have anything specific in mind. Within the first six months, however, we came up with several products. We've been running hard ever since to keep up with their development.

One of those products is OmniTRACS. A company in Los Angeles spent several years trying to develop a satellite terminal to go on a truck to provide two-way communications and position determination back to the operators. One of the key aspects was developing an antenna that needed to have 19 dB of gain to be at a reasonable power level and a close link to the satellite. It was a complicated problem because we had to point the antenna at the satellite as the truck drove around and went under bridges, for instance.

In thinking about it, I went back to EM [electromagnetic] theory from an antenna course I took from Bill Gordon at Cornell and realized that we could develop a rotating antenna, a rotating fan beam, with a single probe sticking up that didn't rotate so we wouldn't need RF joints. We could build something out of plastic that was inexpensive, in the $60 price range, but highly reliable. A lot of the early antennas are still operating, in fact.

We then needed a way of minimizing interference with the large terminals. We were using fixed satellites that typically were operating with either the VSAT terminals or large dishes for TV transmission. We had to have the trucks drive by those ground stations and not cause interference, and came up with the idea of using spread-spectrum signals, both direct spread and frequency hop signals, and then a way to make use of that on the links with a low-cost receiver.

We needed FCC permission to do this, and the FCC said we would have to talk to different satellite operators to see whether there may be some problems. Eventually, Klein Gilhousen [a Qualcomm cofounder] came up with the suggestion to make the digital signal look like a TV signal. If TV signals were acceptable, then these signals would also be acceptable.

We had also been developing chips for other applications, digital synthesizer chips; we used the technology for this product and it worked out nicely. Now this system is on over a half million trucks around the world. It was our first commercial product and gave us initial cash flow.

D&T: It was very innovative, an applied processor and firmware. It could have been all hardware.

Jacobs: Exactly. At Linkabit, we had visited a number of the defense labs to give lectures—because it was so very early in the game—on microprogramming and how one can use processors to do things that had previously been done by hardware. We applied these lessons at Qualcomm.

D&T: So you were very successful with the truck-based systems. How did you evolve with CDMA [code division multiple access]?

Jacobs: We had a request from Hughes Electronics to look at a filing they had just made with the FCC on mobile satellite systems. They had proposed some innovative ideas, but with more traditional time-division and frequency-swept approaches. They asked us to look through their proposal to see if there were any errors and if there were improvements we might suggest.

Returning with Klein from our second meeting in Los Angeles, it occurred to me that, when you're having a private conversation, there are times when you listen to the other person, or times that you stop to think, or there are gaps between words. Those are unused periods, and it would be nice if you could give the satellite capacity to someone else during those periods, then get it back when you needed it, when you began to speak again.

But with the satellite delay and typical modulations, you can't turn around the channel that quickly. I realized that, with CDMA, the limitation on capacity is interference, so if somebody stops talking, immediately they stop generating interference. If enough people talk, you can get a really large number, so you can design for the average speech activity and benefit from people speaking only a percentage of the time.

That was a first step. Klein Gilhousen came up with the realization that the satellite uses multibeam antennas, but that the beams overlap a bit, so with the traditional technology, we'd need different frequencies on each beam. Otherwise, there's too much interference, beam to beam, and the error rate is too high, meaning we couldn't reuse each frequency in every beam. Spread-spectrum CDMA is fairly immune to interference. We could reuse all frequencies in each beam with only small capacity losses due to the beam overlaps. For a multibeam satellite, the capacity would be much higher using CDMA.

There were a number of these improvements that we realized for the satellite case. We also thought it would be useful on terrestrial communications. This was just after we started the company, so we discussed it with Hughes. Anytime anybody hears about using CDMA for a commercial system, their first reaction is, that's crazy. It takes a few meetings, and, with luck, nobody finds a hole in it. They didn't find a hole; Hughes then supported us to do some computer simulations and build a sample receiver and pseudo-satellite. Everything seemed to perform as we had predicted, but it became clear that a satellite system was several years into the future. We thought about pursuing CDMA for other applications but didn't have the resources; we were still small. We did finish the OmniTRACS. In October 1988, we signed our first OmniTRACS contract, a large one with Schneider International, which was, I think, the largest truckload company in the US. That gave us some resources to look at CDMA.

In October 1988, we looked at applying CDMA to terrestrial use. It began to look very promising. Around

February 1989, we felt confident enough that we had something that might be very useful to the cellular industry. What we didn't realize, because we hadn't followed the industry very carefully, was that the previous year, the industry had considered going from analog to digital. Subscriber growth was increasing, spectrum was a problem, quality was a problem, and so the best way to move ahead would be digital. The argument was between going with frequency division multiple access or time division multiple access, FDMA or TDMA. Some companies had looked at CDMA, but there was a power control problem and a number of difficult issues that made people decide it wasn't promising. In the US there was a yearlong debate between TDMA and FDMA. I believe AT&T (which included Lucent at the time) and Motorola were both FDMA, and a few others, including IMM—the company for which we had originally developed the Ultraphone TDMA phone at Linkabit—were TDMA supporters, as were some of the European companies. There was an industry vote in January 1989, which TDMA just barely won.

So in February, we visited a cellular operator, PacTel Cellular, and said we thought we could do even better with CDMA than with TDMA or FDMA. With TDMA, there was a chance of a three-times capacity improvement over analog, but what the operators had been looking for was 10×—with CDMA, it looked like we could easily exceed that.

By June 1989, we had enough confidence to ask the Cellular Telephone Industry Association to set up a meeting in Chicago, including a number of people—from Europe and the US—working on standards. We made a presentation on CDMA—people came because they were interested in what was going on, but they were skeptical. I myself wasn't sure that, with all these experts, they might see something we had missed and that would be the fatal flaw.

Nobody found a problem. But people were still not convinced that CDMA would perform as we'd said, so we decided to build a couple of base stations and a mobile unit to demonstrate that we had good solutions to the problems everybody had identified.

D&T: So this was on Qualcomm's initiative—there was no one funding this?

Jacobs: We did get some support from PacTel Cellular, both monetary and psychological support in a sense, and the use of their frequencies to do the demonstration. Next, I went to the FCC to see if there was a problem as far as introducing new technology. The FCC said it was fine as long as it didn't interfere with existing analog systems.

In September 1989, after we'd built the base stations and the mobile, we had to decide whether to invite the standards group to San Diego for the demonstration or to wait. Waiting was chancy because the industry was rapidly advancing the TDMA standard, but if we moved too quickly there was a chance the demo might flop. The engineering feeling was that perhaps we should wait. I thought we could make it, so we sent out the invitations. Again, that's where it's useful to be an engineer when you have to make some of these decisions.

We worked right up to the day of the demonstration, early November 1989, and started out with presentations about what people should expect, and what we had done to solve some of the problems. Just before we were going to send people out to the van and to the lab to be on both sides of the call we were going to demonstrate, someone waved at me from the back of the room to keep talking. I had to keep talking for about another hour or so; then I got the signal it was OK to proceed. It turned out that the system had come down. We were using the global positioning satellite system to provide a time reference to synchronize the base stations and to get frequency information so we didn't need an expensive oscillator. The GPS satellite system was still in its early stage of deployment; a satellite had come over the horizon with an error in it, and threw off the two base stations.

That was the delay, but afterward, everything worked well, which convinced some of the manufacturers and operators that CDMA was indeed promising. That led to our business model: licensing many manufacturers to make CDMA equipment, providing a lot of technical information and the rights to use the intellectual property. We were paid a license fee up front, then a royalty. The license fee was essential because we didn't have the

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money to go to the next step, so the fees, as well as the cash flow from OmniTRACS, let us keep moving ahead.

D&T: How did you come up with that model for licensing technology (obviously a very lucrative model and one many have followed)?

Jacobs: We wanted to find a model that would give us a recurring source of income. Enough people were skeptical about CDMA but were willing to sign up to pay a royalty because chances were they would never pay it, but this way they were protected in case it did work out; they'd have the rights to use the technology. It took quite a while to get agreements signed. The first one was with AT&T, the second, Motorola; the third one was with Nokia.

D&T: Why did you stop there? Why didn't you decide to go into manufacturing as well?

Jacobs: It was one thing to show that we had solved some problems with CDMA, but then we had to show that it could indeed be commercial, that we could build infrastructure of reasonable size and complexity. Some people still said, well, maybe CDMA might work, but you need so much computing power and so on that it'll never be practical. Others said it would violate the laws of physics, even after seeing it work.

While we developed the handsets and the infrastructure—to demonstrate that CDMA was practical—all the manufacturers were focused on building TDMA equipment and trying to finish the TDMA standard. We developed three chips to go into the handset (one chip was common with the infrastructure) and two other chips for the infrastructure, using the ideas of software chip design that we had started originally at Linkabit.

Exactly two years later, in November 1991, we invited everybody back for a demonstration, this time with commercial-sized equipment. This demonstration was so successful that the CTIA invited manufacturers and operators to come to a meeting in Dallas to examine the performance of the different technologies for cellular use.

We made videos while talking over CDMA phones as we drove the van around so you could see the terrain, buildings, trees, and shadowing effects of various kinds. Then we demonstrated being able to listen to both sides of the conversation under different circumstances. We brought the video to the meeting, and used high-quality loudspeakers to reproduce the conversations. The demonstration sounded great, whereas the TDMA sound quality was a disaster.

D&T: How were you able to generate enough traffic to show its value in terms of no interference and so on?

Jacobs: We had set up a significant amount of testing capability—inviting many other companies to suggest tests and be there to process the data so nobody would think we were doing something under cover. We were open with the whole process, one aspect of which was capacity testing. We set up a number of different vehicles to go out with several telephones in each, and then a simulator to generate traffic as if there were many more users. We set up enough cell sites that we could have the interference from the neighboring cells as well as the cell in which we were embedded and made a number of capacity measurements.

D&T: It must have been a huge effort to pull together consistently. It sounds like a great challenge. Did you handle all of this?

Jacobs: Yes, and we had people assigned to different aspects of it, including the logistics of getting a fleet of trucks out. We did a demonstration in Manhattan where we had a van with the PCs inside. It was the switching center for a small network that we used as a demonstration. People would walk by, look in the windows, and run—this was in the middle of the night; we figured they might be drug dealers who thought the van was a police stake-out.

By running a number of tests over a two-year period, we'd shown that the CDMA network was reliable under many different conditions. The CTIA then recommended to the TIA that they go ahead with the standard for wideband spread-spectrum signals. Thus, two digital standards were developed, one for TDMA and one for CDMA.

D&T: Do you see more interest from the European entities, or Asian, or American? It sounds like most of the experimentation or tests were done in the US, but you had good representation from Europe, and potentially from Asia.

Jacobs: European companies came to some of the demonstrations but had earlier decided on going with the TDMA-based system: GSM. Their main concern was not capacity—in the US it was capacity—but a common technology that could support roaming across all European countries. A number of the governments signed a Memorandum of Understanding that they would only use GSM [originally Groupe Spécial Mobile, now Global System for

Mobile Communications], so there was really no opening for CDMA until the third generation of cellular.

After the 1991 demonstration, we made presentations on CDMA in various Asian countries, including China and South Korea (Japan had already decided on TDMA, so they weren't open to making the switch to CDMA). Korea had a growing consumer electronics industry but was always lagging behind the Japanese developments and therefore needed to compete on price. We said, There's a chance, if this technology does become commercial, to gain an advantage because the Japanese are going with TDMA initially. After much studying of the technology and participating in the CDMA test program, they decided to go ahead with CDMA, so Korea was really the first country to adopt CDMA as a nationwide standard.

The standards process started in April 1992 and took about a year and a half to complete. The CDMA physical layer wasn't changed, so the chips that worked for our 1991 demonstration still worked under the standard, allowing more rapid commercialization.

The first system then went commercial in Hong Kong around October 1995. It was seven years, from the time we came back in 1988 to look at CDMA for cellular, to 1995 when the first system went commercial—a fairly short period.

Interestingly—of course, we had developed phone and infrastructure—we were manufacturing the phones here in San Diego. We shipped them to Hong Kong and South Korea for the system startups in both countries. Usually, the consumer products come from the other direction.

D&T: Did the manufacturing companies essentially label them with their own labels?

Jacobs: No, the first phones were labeled Qualcomm. We set up a joint venture with Sony to manufacture the phones. We also made the chips available to various licensees, so they could build their own branded phones using the chips, but we were first to market, because we had been working on it that much longer.

We got off to a good start and provided good customer support; we thought about how to support the operators and the sales-selling points. We ended up with a very good share of the market for the phones.

We continued to make chips, then sell them to both infrastructure manufacturers and handset manufacturers. It became clear that we couldn't be in all of those businesses. When you sell to a handset manufacturer and you're making your own handsets, they say, Well, you can't tell us you're not going to give your own manufacturers the chips and software first and later give it to us. That was a tough argument, even though we weren't following that path.

We decided to focus on the chips; we sold the manufacturing business to Kyocera here in San Diego, and the infrastructure to Ericsson.

It was also clear there would be a number of manufacturers in CDMA, and we could either focus on the manufacturing or on the chips and technology development, but it was hard to do both unless we were much larger. We decided to focus on the chips; we sold the manufacturing business to Kyocera here in San Diego, and the infrastructure to Ericsson.

D&T: It seemed like a courageous decision. Was there a lot of controversy internally or was it an obvious choice?

Jacobs: It's a difficult decision to sell off divisions, particularly a handset business—over a billion dollars a year in revenue. They were fairly substantial businesses with many employees, so one of our requirements was that people would maintain their jobs so that both the handset and the infrastructure would remain here in San Diego, and therefore we weren't putting people out of work. Luckily, we managed to do that and get two strong CDMA partners in Kyocera and Ericsson.

D&T: At this time, Qualcomm is viewed as a major leader in its industry. Your revenues are up to $5 billion a year and growing substantially each year. What do you view as the next engine of growth?

Jacobs: With respect to the near term, clearly CDMA is continuing to grow. For third generation, most GSM companies and manufacturers have chosen WCDMA [wideband CDMA, also called UMTS] so all third-generation cellular is going to CDMA, ensuring that the technology will grow substantially. We continue to develop enhancements of the transmission capability. Our EV-DO [EVolution, Data-Optimized] technology achieves peak rates of 2.4 (going up to 3.1) megabits per second [Mbps], averaging several hundred kilobits per second on the forward link. An EV-DO revision now being completed raises the peak data rate on the reverse link from cell site to over 1 Mbps.

The chip capabilities, with Moore's law, roughly double every couple of years, and therefore we can do more. Even with multimode communications on the chip—that is, CDMA and GSM/GPRS, for example—much of the chip is devoted to other functions, so we're now in the business of developing powerful, low energy consumption processors to go on the same chip as well as digital signal processors. We're also developing additional capabilities—GPS receivers, camera functionality, camcorder functionality, high-quality stereo, interactive video, game-playing, 3D graphics—to go on chip. We think the devices over the next few years, and the phones themselves, are going to generate much interesting work for us and exciting uses for consumers and businesses.

With a high-speed Internet connection and the right operating system on the phone, you can download new system software to the phones. We can continually upgrade the phones and give consumers a choice of applications, from games to business applications to—if you attach a sensor to the phone—various medical applications. One that's being introduced performs blood tests for sugar content for diabetes patients.

There are lots of possibilities going forward. Qualcomm has had to decide whether to integrate all these capabilities onto the same chip or go with ancillary chips. One consideration is that phones are run by batteries, so we want very low power, low cost, and small size. Therefore, we're integrating as much functionality onto our digital chip—our MSM chip—as possible.

We have centers focused on getting more computing power on chip while consuming less power. A few years ago, we realized we're probably better off developing chips with two processors: one optimized for speed but with a little higher power consumption; the other optimized for lower standby power computation, but with much lower performance and depending on the application, we use both processors appropriately to minimize power consumption, while delivering high peak performance. We're also developing improved digital signal processors—we have two on each chip doing a lot of the general computations; we're adding graphics engines on chip, and so we're developing expertise in many areas well beyond the communications capability. That gives us an edge in supplying chips into the markets—the WCDMA, CDMA2000, whatever new standards come along. We continue to license the expanding CDMA IP.

D&T: Does Qualcomm license processors or other IP from others?

Jacobs: Yes, for example, the basic processor is an ARM processor today, and so we use that basic technology, then make a number of improvements.

D&T: You have a platform for many different applications in many areas with a base of WCDMA or CDMA technology. How do you see the coexistence of the 802.11 and 802.16 technologies with the CDMA? Do you see them as exclusive or complementary?

Jacobs: The local-area-network capabilities are complementary. Other than that, I have not believed that one could have independent businesses that could sell 802.11, a local-area, hot-spot type service. With companies such as Verizon and Sprint launching nationwide networks based on EV-DO technology, offering nearly unlimited data at a fixed monthly amount, it's more important to have the flexibility to use wireless everywhere than to just be able to use it at hot spots. Therefore, when you visit a hot spot, you'll stay on your wide area, rather than local area, coverage if you have to pay extra for local area.

I see several ways in which the 802.11 standard expands. One is that operators may use it to supplement service delivery, utilizing a phone that can switch between the wide area and the local area, but operate without additional charges.

By the way, the wide-area data rates are high enough now that customers have the ability to download music files or whatever else they might want to download.

D&T: Is Wi-Max your competition?

Jacobs: Wi-Max has one tremendous advantage over WCDMA, HSDPA, and over CDMA2000 1xEV-DO—it's got a better name. One still needs the technology, however, and so people are working on the standards. I don't see any technical advantages of Wi-Max over third-generation CDMA approaches being followed right now and with continuing evolutions in the pipeline. The CDMA approaches provide at least comparable—and probably enhanced—performance.

But the key is time to market. We work with operators on licensed spectrum. That's important for wide-area coverage; for local-area coverage, we can get by with unlicensed spectrum, but unlicensed is more difficult over wide areas.

Operators are making major investments in 3GCDMA to provide wide-area coverage, high data rates, ubiquitous coverage and many new services. Manufacturers are turning out a wide variety of devices at steadily decreasing prices. Therefore, it is hard to come along later with a technology that doesn't offer significant technical advantages. Having said that, there are some fairly major companies trying to press ahead with fixed WiMax and later an incompatible mobile WiMax. Thus, local area will be complementary, but mobile WiMax will probably be competitive, if in fact it finds a way to proceed.

Now, part of being competitive is evolving to voice-over-Internet protocol (VOIP). One of the issues we're working on is supporting high-quality and high-capacity VOIP over cellular using radio carriers that are optimized for packets, such as EV-DO rev A. Voice has always been carried as packets in CDMA, even on the backhaul between a base station and a base station controller or switching center. It's all packetized, so it's not the packets that impact quality and capacity but rather the delay variability in the arrival time of packets when the carrier is optimized for packet switching. Possibly some packets arrive late or out of order, so we need a buffer to smooth out the flow. We have to be clever; we can't use too much buffering because we'll end up with an unacceptable delay in the two-way conversation. On a push-to-talk or something, VOIP works fine.

You want enough buffering so that most packets are received in time to be put into the vocoders. You can lose a few of them and still wind up with very high quality. There's a trade-off between the quality both on the sound and delay and the capacity that we can achieve.

D&T: Would you like to see Qualcomm take a strong position in both IP networks as well as …

Jacobs: … we're trying to use the IP networks as they evolve, but as far as the air interface, we have to work on reliability and security issues.

Our results show that we will probably achieve VOIP capacity and quality that equal or exceed voice on circuit-switched carriers, so in the future we'll probably only go with packet switching on the carrier as opposed to mixing both packet and circuit-switched data.

D&T: What is your main strategy with respect to portable devices such as laptops, as opposed to cellphones and PDAs?

We have been working on an area called BREW [Binary Runtime Environment for Wireless]. It's an end-to-end ecosystem for system and application software being developed around the world.

Jacobs: Separate PDAs are probably things of the past; smart phones do all that. It's probably more of a configuration issue now; for example, the Treo has a nice-size touch screen, and good aspect ratio; and with the Palm operating system—that's one with a good form factor. But all phones are becoming smart devices.

We have been working on an area called BREW [Binary Runtime Environment for Wireless]. It's an end-to-end ecosystem for system and application software being developed around the world. The idea is to market new features and services to operators around the world, downloading the software to phones when selected by individual users. The software is protected by a digital signature added after test, so that users can be assured that the software didn't change between testing and delivery to the phone.

D&T: From a geographical aspect, how do you see China? Is China getting more of this technology? What are the differences between China and other places in the world?

Jacobs: With well over a billion people, China is a rapidly growing cellular market and will continue to be so. It took us about 10 years to get CDMA into China. We worked with them since the early 1990s. We did a demonstration there, which worked out well. We translated the standards into Chinese, but it was always difficult to move ahead. In China, there is always the feeling that it's a huge market; therefore, they will provide the market and you provide the technology, and everybody proceeds happily. It took 10 years to convince decision-makers that it doesn't help to have a large market if you also can't make a profit. So, there's balancing between value received and cost to be done.

Right now, in China, Unicom is running a large CDMA network. There's also a decision pending on the

2.1-GHz spectrum assignments of the third generation. China hasn't yet decided who they'll license; there were four favored candidates for licenses. Consolidation is possible, so there could be fewer licenses. There's an additional form of CDMA called TD-SCDMA that runs on unpaired spectrum. China publicly views TD-SCDMA as homegrown although it is based on some work done in Europe and on our developments.

D&T: Is Qualcomm doing its development almost exclusively in the San Diego area, or do you outsource? This is obviously controversial, depending on your viewpoint. What is your view about outsourcing and its value?

Jacobs: It's impossible to get enough engineers in the US that are well trained and capable of doing all the R&D that's needed. We're still in an expansion mode, expanding our research and development, because we see such a growing worldwide market ahead. We continue to expand here in San Diego. We've established centers in a number of US cities, most recently in Research Triangle Park, with work on CPU improvements, and in Austin on digital signal processing. In Boston, we're doing some of the 802.11 and 802.16 work. Our earliest center was in Boulder and we have others in Silicon Valley, Portland, and elsewhere. Off-shore, we've established an R&D center in China; we've established two in India, and, of course, we have significant operations in Europe as well.

One issue we've run into is that a lot of engineering students here, particularly those with advanced degrees, are foreign-born. To hire and use them in the US requires H1B visas, which are becoming increasingly scarce. We ran out of our H1B allotments in the first few months this past year.

D&T: So your preference would be to hire locally, or to hire where you find the research and development?

Jacobs: We hire where we find good people. I think that means we will continue to grow here, but we will also be going elsewhere.

D&T: You do have a wonderful track record of supporting education over the years. You've provided substantial grants and donations to UCSD. Can you talk a little bit about your High-Tech High?

Jacobs: One of the problems in the US is that a smaller percentage of students go on to study science and technology. Many students have been avoiding college preparation K-12 science and mathematics courses. A number of years ago, we helped set up a charter school called High-Tech High to encourage students to pursue math and science preparatory courses and to motivate them to continue on to college. The intent was not to take the highest-performing students, but rather any student who would make the effort to apply and come for an interview and then to select by lottery distributed over postal zones. We attracted a CEO (Principal) and teachers who have made an exciting program for the students and one that is now expanding to additional schools. Qualcomm provided some support. My oldest son, Gary, became interested in it, and in fact left Qualcomm to focus in particular on High-Tech High, serving as chairman of the board and with his wife Jeri-Ann providing substantial financial support and guidance.

The school is off to a strong start. We ended up with a good curriculum and a good, project-based way of teaching students. Students interact with one another. Teachers have actually applied from around the entire country. The first graduating class all went on to either four- or two-year schools, mostly four-year schools.

The Gates Foundation provided money to help replicate this in a number of other cities around the US. In fact, there's even some interest in China now. We've added High-Tech Middle School and High-Tech International School here in San Diego and several in other cities. These students' performances have been excellent by all measures. Hopefully, a number of students from High-Tech High will attend UCSD and some of the other very good engineering schools, and contribute to a buildup in engineering enrollment.

Also, the school is about 50% girls and 50% boys, so hopefully we'll reach a better balance.

D&T: Funding education and research has certainly not kept up with overall budgets. Are you involved in advice and recommendations to the government?

Jacobs: We do a lot of lobbying in different areas because of our international business. There're always a number of political and economic issues that get governments involved: intellectual property protection, things of that type.

But I always go back to my own experience at MIT: I spent two years as a member of the Research Laboratory of Electronics, which was well-funded by the joint services. RLE didn't have to specify in advance which research was going to be done; we did have to report on it after the fact. If anyone ever calculated the cost vs. value received, it would become clear that it was a tremendous investment, and a good model for going forward. But the Defense Department doesn't provide that level of support any longer. The National Science Foundation and the NIH do provide support, but we need to be doing a lot more. The payoff is huge.

D&T: Do you believe that strong research funding, from pure research through pre-competitive, as the government calls it [like that available from the National Institutes of Standards and Technology]—are good investments?

Jacobs: They're very good investments from an economic calculation, but essential from a US calculation. You mentioned this question of outsourcing or work going to other countries: Other countries are highly focused on education. The more successful ones have provided a very good education to reasonably large groups of citizens, so many more engineers are being educated in China and in India than here.

If we're going to provide and maintain any leadership, it's going to be through developing more well-educated students to found—and work in—businesses and to innovate. It's essential for us to recognize that.

The problem is that most of these programs have a long-term payoff; most political decisions are based on very short-term issues. We just have to keep working at it.

D&T: What would you counsel today's high school students and kids making decisions in terms of their careers? Is engineering a good career?

Jacobs: Engineering is very exciting, as are the sciences in general. They're critical to our further economic growth, so I think that jobs will be available. Yes, I strongly recommend [engineering]. I also tell students that change is always going to be with us; it is, in fact, accelerating, and therefore it's very important to get as basic an education as possible. Students shouldn't take only courses in the most current technology but in basic materials, science, mathematics, and engineering. Students will go through many changes during their work lifetimes, so it's important to have a good background; later on, they can always get the applied knowledge.

D&T: Thank you very much for a most engaging interview.