Qualcomm
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Presenters
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Steve Mollenkopf, Chief Executive Officer
James Thompson, Executive Vice President of Engineering, and Chief Technology Officer
Alex Rogers, Executive Vice President and President, Qualcomm Technology Licensing
Cristiano Amon, President
Akash Palkhiwala, Executive Vice President and Chief Financial Officer

Moderator
Ladies and gentlemen, please welcome executive vice president, engineering, and chief technology officer, Dr. James Thompson.

James Thompson
Hi. Thanks. A lot of you don't know me, I'm sure. I've been at Qualcomm for a long time. I started in the CDMA project. And so, that was a very interesting experience. Lately--or, in recent past or for, let's say, the last 18 years, I've been head of engineering for QCT. And then, about two and a half years, I've been the CTO of the company, which means I've taken over all of engineering. That's what that means. So, I have all of engineering at Qualcomm.

So, we--I think we have a pretty interesting technology story to tell. I'm going to start off going through our technology strategy and think of that as we have all these incredible assets from smart phone and we're applying them to other businesses, as Steve said. And I'll explain how we do that and some of the things that we do with our products in order to make that happen.

And then, 5G. We have 5G leadership and the 5G leadership story is really about investing way ahead of the industry. I'll talk about that, too. And then, our mobile platform. I'm not--there's many dimensions to our mobile platform. I'm just going to talk about a few of what I think are the most important parts. Okay.

So, Qualcomm is really an innovation factory and that has to do with the people, the culture, the organization, and starting with the research. So, we have research teams that their timed horizon is about five to 10 years. And you can think of these research teams as very similar to the original CDMA project that we had. So, they're looking at technologies that go out fairly far. A lot of the work that they do feeds into the standards. And the culture is very similar to what it was in the CDMA days when I was involved in that project where it's pretty academic, but it's grounded in practical business considerations, practical technical considerations. So, it's very, very healthy culture, I would say.

And then, we've expanded that beyond wireless. So, now, we have an AI research team. We've had that for quite a while. I'll talk about that. We also had a multi-media research team for probably almost 20 years now. So, very successful teams.

And then, if you look as the company grew, we started QCT way back when. And QCT was pretty small in the beginning. We were doing one chipset a year. And then, as it grew, it got much more complicated. We started out in one building and then we were in multiple buildings and then we're in multiple cities and then multiple countries. And so, we have very large operation in QCT. And so, the culture there necessarily required that we be very focused on our customer, on-time delivery, predictable execution, which is very different than research. And so, as that grew, we needed to, I would say, create some intermediate research groups, which we call technology teams.

And so, these technology teams, they're looking two to five years out. And these teams, we have probably two dozen of these teams. And examples would be graphics, video, modem development. And so, what we do is we have these teams that are focused on that. They work with research teams on one side and then deliver the products on the other side. So, it's a very healthy environment. And each one of these three phases, each has its own micro culture, I would say. But, it's been very, very successful.

Okay. So, our technology portfolio is really--it's the best in the industry and it really--where it comes from is the smart phone. So, as we were developing smart phone, we started working on smart phone 20 years ago, around year 2000. And so, each one of these technologies that you see up on the screen are things that we initially started organically within the company. Now, I'll just tell you--just go very briefly through it.

So, wireless, we're very well known for 4G, 5G, obviously. One technology I'm not going to talk about today other than right now is Wi-Fi. So, with Wi-Fi--we actually have a fairly long history. We're doing quite--we have very strong business there. We're really one of two companies in the world that really drives Wi-Fi. And our Wi-Fi 6 products are just coming out. We have access points now. And since products are just coming out, we've had a chance to benchmark ourselves against that next best competitor and I think we're doing very well. And so, I'm optimistic about our position in Wi-Fi 6.

I'll talk on RF front-end. This has been a 10 year journey with some ups and downs. And I'm going to talk about that later on because I think that requires some detail.

On the application processor, may not be aware, we're very well known for modem, but application processor, I think we're the strongest--certainly the strongest company in mobile. I think we're the strongest company in the world. There's many, many dimensions to measure that. But, for example, mobile GPU, I think we're the best. We have the best AI--dedicated AI processor. DSP, I think we're the best there. Camera, video, a lot of these multi-media technologies. There's a very strong portfolio there. And then, there's other components that we do. Like, fingerprint would be an example.

But, anyway, the real--the summary here is that we've got a very, very broad and deep technology portfolio.

I need to talk about AI because it's something that is affecting everything that we do. It's affected--well, we've been working on AI for about 10 years. And we have a research team. I mentioned that before. And that research team is focused on energy efficiency or power efficiency. So, that's something that maybe is different. So, we have a different focus--very different focus than the cloud guys, for example.

So, what we do is we have the centralized team, a research team, and there's a lot of--actually, we're getting a lot of recognition from academic conferences and so forth at this point because I think what we're doing right now--what we started doing 10 years ago is very--becoming very relevant.

So, if you look at how we use that research investment, it goes into all those technology teams. Virtually, every technology team that we have is affected by AI. An example would be, for example, camera. So, with camera--I'll just give you a quick example. If you're processing an imagine, if you process your face, for example, you would prefer to do that differently than processing grass. You're standing on the grass. And so, if you don't--if you can determine what is a face, what is grass, what is sky, what is whatever, then you can process things differently and end up with a better result in terms of image quality. That's just an example of how we're using it all over in our technology teams.

Also, we have something we call Qualcomm AI Engine, which is--you can think of that is--we're in our fourth, going on to our fifth--about to release our fifth generation. And that's hardware at the base. So, at the base there is CPU, GPU, and then also dedicated AI processors that are super efficient. And then, on top of that, we provide software for both our internal people to use and then also our customers to use. And then, that affects almost all of our products today. Like, I would say, probably 90 percent of our chipsets that we sell have some AI component to it. So, it's been a long-term commitment and I think it's something that's very important to our future.

Okay. So, our technology strategy, like I said, is leveraging all of this technology that we've developed from the smart phone. Everything that you use in your smart phone--everything you like about your smart phone is there. We own that technology. We can do whatever we want with it. And if you look, you'll see that every one of our adjacent businesses outside of mobile takes advantage of that technology. Every single one.

And so--and then, we also share products as well. So, there are products that we do for mobile that we preplan to be used in some of these other markets. And I'll explain that. I'm going to give you an example--one example and that's in automotive, which is our long--most longstanding adjacent business.

So, very simple example is telematics. So, with telematics, that's modems in cars and at this point, there's--I think in the U.S., it's more than 50 percent of cars are now going out the door with telematics capability. So, what we do is we do a modem design, no application processor in it, a modem design, and then we pre-integrate Ethernet, for example, which is not required in mobile, but we--it doesn't take up much area. It's very simple to do. So, we preplan certain parts to go into the automotive market. That's one example. So, we can take advantage of the scale that we have in mobile and then just apply it to automotive.

Infotainment, a little more complicated. Infotainment is a business that we've done extremely well in and I believe Akash will give you some ideas about where we stand in that. But, we're winning almost everyone at the high end. And really, it's surprising and it's not because if you look at the strength of our technology, the application processor technology we have, and we can apply that to automotive. It's very powerful. Other competitors in automotive don't have the scale of investment that we have in those areas.

So, I'll give you just a quick example. So, in a smart phone, you're running this one display and you might run an external display at the same time. So, it's fairly limited. But, in an automotive product, it can be running many, many displays. And also, the aspect ratio of the displays are much wider. And, in fact, you might want to put multiple displays together, so you need to synchronize those displays. And so, those are just little tweaks to the design that we need to make ahead of time.

And then, if you look at instrument cluster, instrument cluster, that's the thing that tells you how fast you're going and gives you safety warnings and things like that. There are additional requirements associated with that because an instrument cluster, you want to run a safe operating system to run it. And you want to be able to reset infotainment without affecting your instrument cluster because you don't want that to all of a sudden go away. So, it's very important that it's safe. It's considered safe from a technical sense.

And so, there are just simple things that we do in our design up front in order to make it safe. And there's things like running multiple OSes. So, you need to--you have a safe OS. You have a--like, Linux, for example, on your infotainment. So, you're running two different operating systems. You need hardware virtualization. So, you need to have that in the hardware. And then, you run a hypervisor on top. That's how you do it.

And then, there are things like context switching in GPUs. You need to be able to jump between the two without affecting the other display, especially when you have a safe display. And so, there's a lot of things like that that we do that we build into the design out front so that it can be supported for infotainment. And so, that's why it's very, very hard to compete with us, actually, in infotainment because of--we make these little changes and then they go into the infotainment product.

Okay. So, ADAS is something that's--we're looking out to the future. We've been working on this quite a while and I don't think--we haven't advertised it too much, other than some of the demos that we've done. But, it's a very similar story in that we're taking assets and we're taking--we're actually sharing some products with other businesses and we're adding the requirements in for ADAS. And I think the--one of the headliners for that, maybe two. One is that anybody who uses our infotainment is going to have a platform that they're familiar with that they can leverage their own internal development over to.

And then, also, we have--neural processing is something that--AI is something that is very important to those customers. And we have a very, very strong position in terms of power efficiency. And that's something that for automotive--you wouldn't think it, but automotive power is super important because you don't want to have any active cooling. So, active cooling is super expensive. If you can just bolt it down to the chassis and suck the heat out that way, that's much better--a much better approach to doing it. So, I think we've got a very, very strong story in ADAS as well.

And then, also, there's a lot of different sensors associated with ADAS. Again, we're leveraging a lot of our technology and we're working on some of the sensors. So, anyway, very--I think very compelling story. I'm very excited about the automotive business.

Okay. So, I'm going to talk about now 5G--our 5G leadership. And that's mostly, again, a story about us investing well ahead of the industry. Okay. I can give you a little bit of a history lesson. We are--been working on wireless for 30 years. So, this is something we've been doing over and over again. And I'll try to explain to you how we go about doing this. And it's very consistent every year--from year to year on how we approach this.

So, if you go back to the CDMA days, we had, obviously, a very good idea. And in order for us to convince people, we didn't just write papers and things like that. So, what we--we had to actually design the system end to end. So, we created this end to end system design capability, which is very unusual, actually. And then, we had to build the system ourselves. So, we designed it. We had to do prototyping of the system end to end and test the whole system. And then, demonstrate the system publicly, prove to people that it actually worked. And so, if you think of that, that's our playbook. So, we have that exact same playbook.

So, as we went into 3G, of course, a lot of you know DO. We did DO, which was very different. It was an IP based network. And we did the exact same playbook where we did an end to end system design. We prototyped the system, proved that it worked, and then brought it to the standards. And so, again, in 4G, we had an internal program called ultra mobile broadband, we called it internally. Again, there, that was an OFDM system, MIMO system that we then continued--we brought that to--then the standards collapsed. So, 3GPP and 3GPP2 collapsed into one thing and we brought that to the collapse standard.

And again, in 5G, same thing. This time, some of the requirements or what we're doing is different--very different than 4G. But, there also is a lot of leverage between 4G and 5G. So, leverage, like OFDM, leverage like some of the MIMO concepts but it's done very different. But, the focus on 5G is extremely high efficiency, opening up new spectrum, and then adding these new services that Steve talked about.

Okay. So, we invest this chart. Really, we--it's to say that we invest for the long-term in these--in wireless in particular. And we've spent $60 billion so far in R&D that just--which is an astounding amount when that was all added up. I have to say I was amazed. But, if you looked at how we organize ourselves, it's--again, we have this wireless research that's done. And these teams do these end to end designs. And if you look at it, it's not just a group of people that walk into a room and go, okay, let's do an end to end design. There's a bunch of work that goes on prior to that, informing that design.

For example, we have decades--actually, the entire history of the company of teams working on channel coding, for example, which is a very important part of a communication system. Also, MIMO, OFDM--or, I should say, OFDM, probably--we've been working on that for about 20 years. And so, that informed our design in 4G and then also 5G. So, we have these--think of it. We have teams doing end to end system design, but we also have research initiatives going. A bunch of these research initiatives going in parallel that feed into that system design.

And then, that--from that system design, what we do is we take--we prototype again, we prove the system works, we typically demo. We've done a lot of demos in 5G at Mobile World Congress. And then, we take those designs into the standards. And then, ultimately, the standards produce a result and then we commercialize. And then, I think it's probably important to understand that the fact that we commercialize after that, we create products. In part, we have an advantage on the product side because we understand so deeply the technology, but then, we also feed that back into the research that's going on to keep things grounded. So, anyways, it's very virtuous cycle, I would say.

And then, maybe one other point I'll make on this chart is that you'll notice that when we--when 4G was released or 5G was released, it wasn't just one release. There's many, many releases. Like, between 4G and 5G, there was seven releases, I believe. And with 5G, my expectation is it'll be very similar to that or maybe even more.

Okay. So, when we talk about our inventions, our innovation, we--our focus is very much on foundational inventions. And what I mean by that is there are things that you can do with the standard or the design of 5G, for example, that make it much better. The capacity goes way up. The data rates go way up. There’s some vector of dramatic increase, let’s say.

And then, there are pieces of the standard where--I would call them implementation details where there's ten different ways you could do it. And so, you can pick one of them, and it doesn't matter which way you do it. Our focus, because we're doing this system design, is really about these foundational technologies.

And I'll just run through a few of them. Advanced channel coding--remember I said that that's really the heritage of our company. We have some of the best channel coding people in the world that work for Qualcomm. And with 5G, we picked LDPC (sp) as the channel code. And so, why does that matter? It's because we need to, one, be able to handle these huge data rates and also very different packet sizes. So, really giant packet sizes for data transfer, and then, for voiceover IP, very small. So, you have to have flexibility. You want to be able to support retransmissions if you, say, packets--or the packets get lost. And so, there's a lot of innovation associated with that.

Then, massive mimo (sp)--this is actually one of my favorites. So, we've been working on mimo for a long time. We had mimo in 4G. But, what's different about 5G? So, it's really the massive part that--a practically implementable massive mimo. And what that means is what you can do for a given piece of spectrum is you can get a lot more capacity from it. So, traditional--like 4G mimo--what we would do is we would take--we could produce a data stream--or let's say up to four data streams, and send it to a particular phone at a particular time, but only that phone. And then, we would find another person in this audience here, and we could send data, four streams to that person, maybe three streams.

Whereas, with massive mimo, it's also multiuser. So, you can send four data streams. You can send four at the same time, four data streams here, four data streams here, four data streams here, and not interfere at all with each of those different data streams. So, what you can do is you can create, in a sense, hotspots in individual's phone. And then, for the other person you've communicating with, you can null out that interference. So, there's a lot of math associated with it. But, it actually works quite well.

So, it's something that will improve the capacity of these networks, and then, you don't have to put in new cell sites because they'll work in the same cell sites that exist. You also can get much better coverage from it. So, anyway, I think a very, very important technology.

Scalable OFDM--OFDM is the--is part of the physical layer, and think of it as these tones that are transmitted in the spectrum. And if you want to have a very wide range of spectrum going from, say, 600 megahertz all the way up to mmWave, you actually want different tone spacings. And so, to do that in a--it's very important that you have certain numerology so that you can reuse the hardware that you have in your--so you don't make the modem cost super high. And then, also you need to have the same tone spacing if you want to share spectrum with 4G, and that's a very important concept as well. So, that's something that's very fundamental to 5G.

Also, mmWave--we've been working on millimetre (sp) for a fair amount of time, almost ten years, I would say. And so, we've--honestly, we started off with mmWave, and I was a skeptic. But, it actually works quite well. Some of you have probably been to our campus and done some demos. It works very well.

Then, flexible slot structure--that's also something that's very important. When 5G was originally being proposed to the range of services we needed to support there were a lot of proposals that said, "We're going to do a different system for each one of these." And what we did is said, "No, let's create this framework that allows us to multiplex all of these different types of services into one system because if you're going to do a system, you don't want to have--what's going to get deployed is the mobile system initially. And then, people are going to go, "Am I going to spend a bunch of money on this system for IoT? Maybe not. I'll wait." Whereas, if you can it all into one system, then it gets deployed ubiquitously. So, I think that's a very important concept. Anyway, these are foundational kind of--these are foundational inventions associated with 5G.

So, what I want to say with this slide is we have release 15 coming out. And the releases, as I said before, are going to be going out all the way out through the decade, through 2030 and maybe even beyond because part of what we've done with 5G is we've made it--we call it forward compatible. We try to make it very flexible. We learned from 4G some of the inflexibility that it had.

And so, with release 15--you can think of release as being focused on mobile broadband. So, that's smart phones. That's what pays the bills for the operators right now. That's why that's being deployed so broadly because they see a lot of opportunity in mobile broadband. Some of the subsequent releases--release 16 will have enhancements to mobile broadband. But, it also--there's a bunch of features associated with these adjacent markets. So, for example, ultra reliable--high reliability, low latency communications for some of the factory applications that we've identified, more CV to X (sp)--so peer to peer communication with cars. We've opened up some additional spectrum in license. So, those are kind of some of the highlights. And then, release 17, in about two months, that will be finalized as to what the work items are in that. But, this is an ongoing thing. Think of it as every year and a half or so, there will be a new set of releases associated with 5G.

I'm going to talk about the mobile platform, and I'm only going to talk about four different areas. One is modem, and that includes our front end. I'm also going to talk about camera, graphics, and AI.

So, our mobile platform--I should say our modem--we used to think of the modem as our base band and then our RF transceiver. And as 5G has come in, it's added a lot of complication, a lot of difficulty in doing design of RF components for 5G. And I'll explain that a little bit later. And so, now, we think of--when we think of modem, we no longer think of it as just the base band

and the transceivable. We think of it all the way to the antenna. And so, that's a very important concept.

So, we have--I'll talk a little bit about mmWave, about what that looks like, and then also our front end and how that ties in with the baseband to improve performance. Start with the base band. So, if you look at products today that are in 4G that we can compare--so, what I've got here is a picture of the Snapdragon X24 and the Intel modem, the XMM7660. And if you look at the size of the--our competing product is quite large. So, we're--it's a factor of four larger. Now, the process nodes are different. So, our estimate is that they use twice as many transistors to product a product that is actually--has a lower spec. It has a 20 percent lower spec from a throughput point of view. Not only that, if you measure, where they do--at their peak rate, their 16 layer, and we put ours at 16 layers, then they end up--and it kind of depends--there's probably a hundred different measurements that we make. But, you can think of it was 10 to 20 percent less throughput on top of the lower spec.

Then, you look at power--and this is, I think, for us, the biggest advantage that we have--is if you take like voicepower, for example, the Intel modem measure--these are measured with products, and you can just go out and buy the products yourself and make the same measurements. Fifty to 60 percent higher voicepower, depending on which voice mode you use. With data, I have 27 to 40 percent higher power. It tends to--as the higher the data rate goes, the bigger the difference tends to be between. So, we have a very, very large power advantage.

Now, looking over on the right side, with the 5G comparison--so, this is us compared to the high silicon part that's out there right now. This is in the same process node. So, there's--the 2.6 times larger is in the same process node. So, I think they're directly comparable. They're using 2.6 times as many transistors to get the same function.

And then, from a peak rate, they're 40 percent lower, and they don't support mmWave. So, I think from a design implementation, from an efficiency point of view, I think we're doing very, very well in 5G. Because the networks aren't mature yet, I don't have a lot of performance data to compare. But, I expect that we'll do extremely well there too, power and performance.

So, why is 5G RF so much more complicated, so much more difficult? One is that there is an order of magnitude number of bands that you have to support, band combinations. And when you have band combinations, you have to worry about interference between all these different transmitters and receivers. So, it makes it very complicated. But, on top of that, 5G is also much wider bandwidth. So, it's 100 megahertz versus 20 megahertz. So, that bandwidth makes a big difference. Also, the peak to average, meaning the signals, instead of being relatively flat, it moves up and down quite a bit. And also there are modes of 5G that are higher transmit power that you have in 4G. So, that combination of things makes it very difficult to do the RF in sub six (sp).

Okay. So now, if you look our position, and we think of this as our position in, not just our front end, but in modem--so, we have, at this point--we have every single component, so power amps, LNAs, switches, antenna tuners, and then, on top of that, we have the modem itself. And then, in each one of these component categories, at this point, we are as good or better than our competitors, in every single one of these areas.

I'll just you a quick proofpoint. I'm sure--filters is something we acquired through the TDK acquisition. And that's been something that we've been catching up on. So, this is kind of, in some sense, a weakness. But, if you look, Band40, for example--the blue line at the top is Qualcomm thin film saw. And then, we have the two competitors below it. And, by the way, the higher the better. That's how you get to read this chart. So, that's lower loss in the filter.

And then, if you look on the far right, that's Band41. So, these bands are on either side of the WiFi two gigahertz band. And you can see that the dark blue, again, is thin film saw. I put in for reference, our BAW 4.0 because those are out in products today. So, it's better than our BAW 4.0. And then, we have the FBAR competitor, which is the bottom line there. And I highlighted the--one the left side of the chart there because what also matters about the filter is not just it's the highest but also it has a very steep roll off at that particular point. So, we also do very well there. Anyway, I thought this was an interesting proof point.

Now, I want to talk about how we use our front end as part of the system, our whole modem system. So, there's a lot of system optimizations that you can do if you own end to end. If you own baseband to antenna. There's a lot of things you can do. So, the first one is a fairly simple example, and that's antenna tuner. So, if you hold your phone, there's antenna--you don't realize it. But, there's antennas all inside the phone. And you can detune these antennas.

And so, what we do is we have a closed loop system with our baseband that makes measurements and then adjusts what's called the matching of the antenna. And what it allows you to do is, on the transmit side, transmit up to twice as much power out of your phone. And then, on the receive side, get--receive as much as twice as much power, or I should say twice is probably a typical kind of number. You could do much more than that, depending on the circumstance. So, anyway, if you see a lot of the high--or almost all the high end phones use this capability at this point.

Envelope tracking is another one. Now, we had envelope trackers for 4G, and 4G was much, more forgiving because of the narrow bandwidth, the narrower bandwidth. But, because of the wide bandwidth, you really have to do a code design of baseband. So, there's a lot of digital pre-distortion that has to be done in the baseband to make this work, and then, also the design of the--the characteristics of the PA. And then, you have to have a very tight integration of the envelope tracker. And what the envelope tracker does is it makes--it puts the PA in its optimal position or optimal bias for efficiency. So, that's really what it does.

And then, if you look--these are just comparisons of envelope tracking to average power tracker. Now, most other competitors are going to be supplying average power tracker. And then, the top line there is max throughput. So, that would be the mode, the modulation scheme that has the highest peak to average. And you can see that there's a very substantial benefit we get from that. And actually, the way to read this is it's on the order to--like close to a watt kind of savings. So, in a phone, that's a lot.

And then, if you go all the way down to the bottom, that's where you're trying to get--you're using the lowest order modulation. So, you don't have--the peak to average is not quite as high. So, you don't get quite as much benefit. But, the transmit power is so high there that you're also saving something like--approaching a watt. So, my point here is that envelope tracking for 5G, I think, is something that is very difficult to do, and it's going to provide huge benefits.

Another one I'll talk about here is smart transmit. So, with smart transmit, we monitor the transmit--the output power of everything that--every transmitter on the phone very closely. And you probably are aware that the FCC has requirements about exposure to RF radiation. And based on that exposure, there are certain limits. And those limits are--depend on what frequency you're at. So, there's a fair amount of complication associated with that. And the typical way of handling this in the industry is you just turn down the power or you say it can't go above this level. So, it always--you'll guarantee that it stays below that exposure limit.

Well, what we do is because we track it all very closely, we can actually transmit more power at times and still meet the limit. So, by tracking it very closely, we can improve the overall transmit power pretty significantly. And that--what that does--at certain times. And what that does is it makes your link margin much better. So, in other words, you can go further away from the cell and it still works. But, it's not just the uplink that it helps. It also helps the downlink because there's actually a lot of communication that goes back and forth when you're transmitting data. And it actually helps improve that communication which actually improves your downlink speed. So, I think it's a very, very important technology that we have that it's hard to do, actually.

And I'll talk about one more case or one more system implementation, and that's in mmWave. So, mmWave is--we do in a module. So, it's connected to our modem. But, the module has a phaser ray antenna built into it. And then, build onto the substrate of the phase ray antenna are power amps, LNAs, and switches, and also a little power management module--or chip as well. And that module then we sell, and there's different antenna configurations, and we sell that module to our customers, and they put them in most cases three modules. And that's kind of the typical configuration.

And then what this--these antenna modules do is they can steer a beam to track the base station. And that's why--any maybe I'll say not just track the base station, but they can even track multipath. So, if you have--if the antennas or the base station is in that direction, and then you turn, and your back is to that base station, you can pick up a multipath off a--a wall, a post, another person, even.

And so, that's why it's pretty robust, is because of this beam steering capability and the beam management. And it's also very, very complex. And so, having baseband understanding the whole system and how to manage those beams is very important.
Onto another topic, graphics. We sell hundreds of millions of graphics cores a year or products with graphics in them. So--so, that provides us a fairly big advantage in that our platform is so ubiquitous that all of the developers optimized their--their software and tools for our platform. So, that's a big advantage we have.

And what is our advantage? It's really the most power-efficient graphics core in mobile industry--or, I--I should say, blanket statement, most power-efficient graphics core. And that's really the metric that we use. The other internal metric that we use is most area-efficient as well. And those two--two statements are true. We--if you think about graphics, you can always get more graphics performance by putting down more silicon, okay? So, absolute performance is really more like a design choice.

But, what you'll find is, because of power efficiency, you end up--it ends up limiting your performance if you're in something like a smartphone because there are thermal limits. You can only dump so much power into a smartphone. And then, I put this plot here to help you understand that. So, this is a measure of the Manhattan benchmark. So think of this as a game, and the benchmark runs for about a minute.

And so, the blue line is our performance over time, and you can see this goes out to 20 minutes. So, this is--like think of this as your kids playing a game. They don't play games for 30 seconds, they play them for a 30 minutes. So, think of it as our product has--the performance stays--that's how we design it, so that it stays flat--or continues on.

This is our next-best competitor. And what they'll do is they'll provide a benchmark that says, "Hey, look at how good they are." And they'll be way up here. But then, if you look at it over time, it actually goes down, and the phone itself is struggling to maintain the balance of thermal power. And so, it moves the performance up and down and up and down. So, that's a very big difference between us and our competitors, and I think that's probably the most important thing.

And so, with graphics, we can use this in not just mobile but that power advantage also. I mentioned that in automotive. That's something that's super-important even in automotive--in almost every industry that we go into. With camera, we--you may not realize this, but we're the best image processing company in the world. And we--if you look at cameras, there are more cameras in the world today powered by Qualcomm than any other company in the world. That's pretty shocking, but that's true.

Recently, Xiaomi came out with their DXOMARK score for their camera. And DXOMARK is a benchmark that is a standard benchmark. And what it does is it just looks at--at image quality plus a lot of video features, electronic image stabilization. There's all sorts of different measurements that go into this. But, it is really the--where everyone goes to benchmark their--their phone--or benchmark their camera, sorry.

And so, with Xiaomi--they just came out with that a couple of weeks ago. We worked very closely with them. And they have the highest benchmark score in the world. And then also, from an image--image quality point of view, we spent a lot of time benchmarking our own ISP and comparing it to everyone else's. And so we're--I think we're in a very, very good position there.

And then, I'm going to show you just one of the measurements that are made in this DXOMARK, and it's image stabilization, so electronic image stabilization. As you are taking a video, how much does it move up and down? So what--what we did here is you just have two phones. One is Xiaomi, and one is the next-best competitor. Every other one is worse than that next-best competitor.

And it's on a board. So, we're not taking the competitor and shaking it up and down and making it look bad, so it's actually exactly the same movement. And what you'll see is that we're walking along--you can see the other one is rocking a little. but--but as you go down the stairs, you can see it's very, very different. And this is the next-best competitor. So, that's just an example--an example of the kind of things that we do with camera. So anyways, I'm very, very proud of where we are with our--our camera and our camera team.

A little bit more about AI. AI is going to change how networks are implemented (sp), along with 5G. Those kind--those two things are going to change things quite a bit. Maybe I'll just explain. If you look at the way you experience AI today--is mostly through the cloud. So, a lot of it is, you click on things, you send pictures in, you do things that is monitored essentially by the cloud companies.

And what they do is they try to profile you, which is how AI is primarily used today. They try to get you to buy things, advertise, things like--that's what it is mostly used for. But, I think that AI is going to have the biggest impact on the edge of the network. So, if you think about, on the edge of the network there's all these sensors that are being--we're digitizing the world, so there's all these sensors.

And like, for example, a video camera is probably the most prolific sensor that exists out there. But, there's lots of different types of sensors. And so, what AI is does super, super well, is it can make sense of data. So, you've got all this data coming in, and it's very good at making sense of huge amounts of data. There's no amount of coding that you could do--that you could do--do that as well as--as AI. So, it's very, very powerful in that respect.

So then, what we believe the way things will play out is that--so, AI has become super-important on the edge. I'll just give you a quick example--like automotive. AI for autonomous

driving is going to be--that's kind of a fundamental technology to make this stuff work. And you would not, for example, do that AI processing in the cloud and then send it back to your car because there's--there's a latency issue there. So, what you want is you want all that processing to be done on the device, in this case the device would be the car, just so there's--and there's a lot--there's privacy reasons, performance reasons, latency reasons to do that.
And so then, what you're going to find is that because of that latency to the cloud, there will be these, what we call, edge clouds. So, you'll start seeing cloud extending itself very close to the network to take advantage of the low latency that you have with 5G. In that case, for example--you could do computational offload, for example, that you could send from your device, not just a smartphone but many, many different devices--cars. And you can do a computational offload. So, there's a lot of different--I'm not going to go into great detail here, but we think that this is going to be a very, very significant driver of the future.

Here we go. We've been spending a lot of time--like I said, 10 years--on AI, and we have a--what we call our--our--in mobile--our Qualcomm AI engine. That's it, Qualcomm AI engine. And these are--just to give you a sense, this is a measurement of power efficiency relative to our next-best competitor. And so, you can see there's different benchmarks here--like, for example, ResNet in on the left. ResNet is a very kind of heavy, image classification benchmark. But, these are the standard benchmarks that are used.

And you can see our performance in power. Mobile net is--is really kind of the lighter-weight benchmark. And you can see we do very, very well in terms of power because that's always our focus. And also from an absolute performance point of view, we also--I could show those as well, but we--we--with almost all cases, we're leading as well.

So, why is that important? So, we've developed this neural processor. It's a dedicated engine. And that dedicated engine is much more capable than a CPU, for example. A CPU is horrible at AI processing, neural processing. If you look at graphics, it's much better than a CPU. FPGAs can be much better than a CPU by a factor of 10. But then, if you go to a dedicated engine like we've developed, it's yet another factor of 10 in performance--or power. And so, it's very important that you do these dedicated engines for neural processing.

And then, one of the--we have a product that is called Cloud AI 100. I'm actually--that's one that I'm really excited about, actually. What we did there--that's for--I should say it's for inference in the cloud and inference on the edge cloud. And what we did is we took our AI engine, specifically that neural processor that we do for mobile, and then we designed it so that it could be expanded up.

So, we expanded that. That's what the little brain to the big brain means. And then, what we did is we laid down multiple instances of that neural processor on a chip with lots of IO. And then we're working very closely with some big customers, and the feedback to--to us is that we're better than two times the performance for a given number of watts. And in the cloud, the watts are--that matters a lot. And so, we think we have a very, very strong position going into this--this market.

So, key takeaways from my talk--scale of mobile investment gives us an unmatched technology portfolio, we effectively leverage a large-scale technology investment into other businesses. The 5G leadership comes from a 30-year commitment to research--5G strongly benefits from a modem to antenna design approach. There we go. We are driving the powerful intersection between 5G and AI. Thanks.