coming in the use of digital on-board processing. You see the use of frequency reuse over and over again, being facilitated by some of these new technologies.

All of this is primarily being driven by the need to try and squeeze more and more capacity out of the spectrum. Essentially, from the satellite perspective there are certain limitations to what can be done in terms of protecting itself from interference and what you've seen really is the drive from the satellite industry to try and get essentially more revenue out of what's being put in space and the way you get more revenue is to squeeze more capacity out of the spacecraft.

Now having said that there are limited things that the satellite industry can do in terms of interference. What you've also seen in the satellite industry is a move from a thermal noise limited environment to an interference limited environment. And so again, there are certain limitations within which that satellite industry operates, but really what's happening to day is the limitations to satellite performance are really driven by the interference environment as opposed to the noise environment.

MR. WOERNER: How would you define that interference environment? Is it very "bursty" or is it uniform using the term that we talked about earlier today?

MR. WENGRYNIUK: Yes.

(Laughter.)

MR. WENGRYNIUK: There certainly is sort of a what you could call more or less stable background noise environment which is from the thermal noise and from sort of interference from adjacent satellites, maybe from terrestrial systems that are always there, and then, of course, you have sort of sporadic interference events as well or diurnal variations in interference as the capacity that's being carried by adjacent systems varies throughout the course of the day. So you see both the temporal component as well as the static component.

MR. WOERNER: We'll move on to Jack Rosa.

MR. ROSA: I'll try to address this from two aspects. One is a CEO of a high tech company, what I think we can do for the world and the second from the standpoint of -- I'm also on the board of directors of the SDR Forum and what the SDR world thinks we can do.

There's no doubt that demand for increased capacity is with us. If you just examine in bios communication the requirements for higher data rates and the attendant features that come with that. It's easy to say give me 384 kilobits. It's hard to produce that. And the reason it's hard to produce that is because you have to have carrier-to-noise ratios and we like to call them Eb over zero, but a 20 dB would be better than what you're getting now with voice. So easy to say, hard to do.

But there are, from a demand aspect, many initiatives going on now. One of the most prominent, I believe, which wasn't mentioned that much this morning, is in defense. Defense is taking the massive leap of faith and they're now going through attempt to build these -- people talk about bandwidth, 2 megahertz to 2 gigahertz radios that handle 30 or 40 different wave forms. It is truly a noble venture.

(Laughter.)

And the industry is struggling with how are you going to solve that problem. In fact, the best we look for today is can we do as good as the old systems were. Maybe the first step is not improve anything, just is it as good as the old system.

But there is some expectation in various places that we can achieve a higher level of performance. Advanced technology will bring that.

It's interesting to watch the transition. As you can see from my gray hair, I've been in business for quite a while and in my youth they used to talk about doing calculations in leak margin based on C to Ns and S to Ns, okay? Now all we talk about S to I or C to I. So the migration has gone from worrying about noise to worrying about interference.

So we're sort of doing it to ourselves.

New technologies, as we talked about which is the advanced services and so forth, bring with them another set of problems. But I think the next generation of technologies have solutions to those problems and I'll save that for the second part.

MR. WOERNER: To what extent are economic factors a limitation on what we can do with software radios? To what extent are those radio technologies going to be expensive and how soon can we count on the cost coming down?

MR. ROSA: Well, there's wide expectations on what STR can do. As with any new technology, it's the great hope. This is going to come in and solve all my problems. I can buy a radio for a dollar. It will get rid of interference and so forth.

Now, sometimes the expectations far

exceed the reality situation, but most of us in the business feel that there is significant gains to be made. There are certainly opportunities here to improve the situation.

The extent to which we can improve it would be a function of to some extent economic issues, people's willingness, like Defense, to take the leap of faith and to realize the economic benefits and that is as much driven by political factors as it is by economic factors.

I think the meat is there. It's how much do you want to eat is the question.

MR. WOERNER: Thanks, Jack. Maybe we could move to the far end of the panel and ask Ray Pickholtz for some opening remarks?

DR. PICKHOLTZ: Thank you. I guess because you wanted a little more provocation --

(Laughter.)

I'm an academic, but I also have a lot of experience in industry, having built things for a long time, but I'll take an academic tact to begin with. The concept of interference, the conventional approach is interference is undesirable, get it down to a minimum or eliminate it and the burden is largely on the transmitter. That's been the attitude. But in fact, there are lots of different kinds of interference. Not all of it is bad. In fact, we know now how to use interference. I'll give you an example. Intersymbol interference. Actually, with the use of intersymbol interference, you can actually improve performance and it's done commonly every day, right now, in most of CDMA handsets. And you can gain 3 to 5 dB that way.

Similarly, the concept of interference is not very different from the concept of thermal noise which is basically you have no _a priori_ knowledge about that you can exploit. But in fact, if you have a system of cooperative users, typically, a multi-user environment, you can actually exploit the fact that there's a lot of _a priori_ knowledge about the nature of the interference and either eliminate it or minimize it to the point where it's not very important. So the problem of going from S to I, S to N to C to I goes back to S to N. That is the only thing that you really can't avoid is the thermal noise effects, whether it be at the front end or some other means.

In fact, we know for about 50 years due to a fellow by the name of Claude Shannon, that there's a way of transmitting things so that you get the maximum possible spectral efficiency out of the system with virtually no degradation at all, providing you don't make a hog of yourself, and most systems today are somewhere between 5 and 10 dB from that limit and it's not the limitation due to interference.

So does this -- are the techniques known for exploiting the ability to eliminate or reduce interference or make it work for you and the answer is yes. There are literally by now thousands of papers and archival journals, but it's gone beyond that. I was very pleased to hear in the last panel somebody actually talking about building some of these systems and I know, I've traveled to Japan where people are building things like adaptive arrays. They're building multi-user detectors. They're building interference cancellation schemes, all of which translate into more revenue for the people who are doing it because let's face it, "it's the interference, stupid." The concept here is that to the extent that you can avoid interference and not treat it as if it was noise you can increase the capacity and therefore get more revenue.

So that's my opening provocative statement. I just want to make one comment. Putting back my hat of a practical person, is this difficult? Yes, conceptually, there are some difficulties, but once you understand how to make chips, you can make these chips -- just as cheaply. You can put 300,000 gigs on a chip just as easily as you can put 20 once you start making them in large amounts.

So I think we're at the threshold of being able to do some of the techniques which would get us to the point where we have an interference, we view interference as not something that's absolutely to be avoided because you're not going to avoid it. It's a question of whether you simply live with it or something about it and that requires a lot of sophisticated digital signal processing, a lot of coding, possibly cooperation between users and adjacent bands and maybe certainly users within the same service provider. But they're coming, I have no doubt. At a later time, I'd be happy to tell you specific numbers and details of what could be achieved.

MR. WOERNER: Thanks, Ray. Maybe we'll move on now to Doug Lockie.

MR. LOCKIE: Well, first of all, I'd like to thank the FCC for beginning this initiative, and I also request that you all keep it going. My experience on this interaction, getting ready for this is it's really valuable to the nation and to the industry. So please keep it going in one form or another, looking ahead to spectrum management as opposed to reacting as we usually have to do.

This whole thing about technology and

what's making advances, I suppose you could say a couple of things started in the last 20 years anyway, have really started this. One is going solid state in most of the communication systems and another thing is these doggone computers and I'll say tongue in cheek, it's all Intel's fault and it's all Cisco's fault and I'll come back to that in a minute. And it's a positive feedback thing here.

As we went from analog radios to digital radios, there's this huge step function and it keeps stepping on up. And I'll say that in two ways. In the old days in the carrier to noise, carrier to interference ratio, you just had no solution except limit your filter and have lots of signal with respect to the noise or interference. Now we can signal process an awful lot of that away. And that wouldn't be possible without modern cost effective computers. All the computing power we had in the Air Force when I was in it in 1969 through 1970 is now today on one single chip coming out of Intel, the Itanium which started off life at

800 megahertz, now running 200 gigahertz. That's an entire super computer, 64 bits, running on one single chip. We'll probably be able to buy that at Fry's or Circuit City or Radio Shack for $100 in five or six years, but that's a 320 million transistor chip and you can buy it in a computer today for $5,000. Huge.

Once you got that computing power, not only did it benefit the radio communications, but it also started making it so that we could build antennas that we could either shape the function instead of having a sectorized antenna that looks like this, with a 3 dB window. You can make that antenna now so it looks within a half dB and then the side lobes fall off like a rock.

And then, you can use that computer to design practically antennas that have things like a cosecant squared pattern, so that you can make a constant flux from the antenna all the way out to the edge of the pattern which would go a long ways to helping this safety band problem where Nextel went off and put out a whole lot of cell sites all over the country in a cellular fashion and then the safety community finally got some spectrum at around 800 megahertz and they can only afford one transmitter or two transmitters per region, so they're always out at the end of their transmission with a very low signal and you've got all these high powered transmitters, so we could use these cosecant antennas to minimize the amount of power you put on the ground right next to the transmitter and maximize the amount of power you put out at the edge of the footprint and that would go a long ways to helping this.

So you've got this combination of computers and solid state and technology feeding on each other, but now let me tell you what the problem is those guys at Cisco and Intel created for us. And Cisco doing the ethernet kind of things. We now need gigabits in the local loop. You used to need a half a megabit, so that you could have a computer talking to the internet and give your screen a refresh. But computers want to talk to other computers at some major fraction of the computing speed.

And today, that's gigabits. So we're flat lined in terms of DSL giving everybody a half a megabit to the internet when your computer is screening for gigabits. So it's a never ending thing of now what we need to take the next generation of productivity forward in the country is to open up the local loop to gigabits so that our computers can talk to each other efficiently and it's never going to stop. It's always going to be an interesting slope to be climbing up, but it's also going to -- should be improving the efficiency of the country.

MR. WOERNER: Are the driving factors that you see at that high range of the frequency spectrum, 10 to 100 gigahertz, are they similar to what we're seeing in other regulatory issues at the lower end of the frequency?

MR. LOCKIE: You know, it could be if you're in a point to multi-point situation, but once you get to say 20 gigahertz or so, most of the time what you're doing is pencil beams. And let's make this 20 gigahertz to 260 gigahertz because that's where the good atmospheric windows are and we've now got the ability to generate radios up in those frequencies.

There, what you've got is spectral efficiency probably now starts becoming how tight can you make your beam. And what we know is all the way down to a quarter degree, we don't have to track the antennas in a typical application. So one of the things that probably what we want to do is try to incite, incent people to put as tight a beam as you can which means a bigger antenna and more careful side lobe control, but we now have the computers to design those kind of antennas and take the cost down.

So the big thing up in higher frequency is how do we get spatial re-use and maybe we decrease the spectral efficiency at the expense of doing that so that we still have cost-effective systems and then later on as the technology comes along and as the business phase grows, then you can start improving the spatial efficiency in a more conventional sense.

A point on that, we could do this down at 900 megahertz for cellular. If we could grow a 70-foot antenna, we could have a 1 degree beam width. By the time you get to 100 degrees, a 5-inch antenna is a 1 degree beam width. By the time you get to 260 gigahertz, about 2.5 inches gives you a degree and so you can have thousands of antennas at each node and re-use the spectrum, half of that, every other beam, every other polarization, so there's a huge amount that can be done on these higher frequencies for opening up the number of bits transmitted per hectare squared.

MR. WOERNER: Maybe we could move to Dale Hatfield?

MR. HATFIELD: Sure. Speaking last, a lot of what I was thinking about saying has been said, so let me try to do something a little bit useful, maybe stepping back, just a little bit from what's been said in terms of what does advanced technology enable and the basically what we're talking about in some ways, I think, and this was covered in the panels yesterday, of course, is moving a lot of that intelligence out to the edge of the network and getting away from that old hub and spokes, centralized controlled-type system. And there's two things driving that. One is just the internet model itself that if you have the intelligence at the edge, then ordinary folks in their basements or garages can invent services and create new services and we obviously have seen that so that's a driving force for putting the intelligence out there at the edge. And I'm reflecting David Reed and so forth. But the other thing, moving that intelligence out there at the edge enables us to do is be much more dynamic in the way we go around, the way we go about managing spectrum. And that's the intriguing part to me.

Ray's already talked about that, moving that intelligence out there. It allows you to do these sort of interference cancellation techniques, cooperating transmitters, all the sort of thing -- cognizant radios, all the sort of things that we've heard about. And sitting here looking at Paul, you sit here on these panels and sometimes somebody says something that changes the way you think about the world. I had one of those at the NTIA spectrum forum. The allocation chart, if you put it up here on the wall, the FCC allocation chart, it's got all these colors and all this balkanization and so forth and somebody then put up where we want to get, the allocation chart looks like this. And all it was was a white chart. And that sort of fascinates me. What it means is that you're moving to a very dynamic, very dynamic system where you can get, where you can pick up this capacity that's available.

We all know, everybody knows this. If you put a receiver on top of this building and take a look around, you find lots of spectrum that's not being used at this moment. And this is moving intelligence at the edge, the edge of the network will allow us to capture that, but it requires us to get away from thinking about this rigid sort of spectrum allocation thing that we've had so far.

So all I've done is sort of picked up

on what people have said before me. Moving that intelligence out to the edge allows us to think much, much differently about structure management than we have in the past.

MR. WOERNER: Thanks. Just quickly following up on what -- a little bit of what Ray said, I think the way we look at interference has kind of changed in the last several years. Historically, we've looked at interference and regulated it from kind of a worst case standpoint. What are the C to I ratio need to be to make the system work? How low do the interference levels need to be in adjacent bands in order to not produce harmful effects? What some of the new advance technologies we've heard about, look at interference, is more from a statistical standpoint. Is the interference too high from a long term average viewpoint? We've heard several different technologies. Error correction codes that are able -- as long as we don't have a long burst of interference to recover things. Code division multiple access systems that are able to handle levels of interference as long as those interference levels over the long term are not too high. Ultra-wide band technologies which potentially have the ability to be kind of CDMA systems on steroids with much higher capabilities. And software radio technologies that we've heard both Jack and Dale talk about that allow us to as long as the whole spectrum isn't full, select those parts of the spectrum that we're interested in. So there's an opportunity to exploit some of these new technologies in this new interference environment.

MR. WOERNER: I think at this point it may be worthwhile to open it up for questions from the audience at the end of this segment.

(Pause.)

MR. REPASI: Okay, well, if there are no questions at this moment perhaps I can move into segment 2 and if there is a question that somebody thinks of during that time and would like to go back at the end of segment 2 and refer to some of the points made in segment 1, that's fine.

What I see out of segment 1 was very

similar to what Brian has just summarized, but I wanted to point out that one thing that I didn't hear as far as driving factors is the end user, what the end user's requirements were. It's interesting that a lot of the statements that were made, people were thinking along the lines of what the interference environment is and what the operating environment is that I'm going into and what can I do to cope or live within that environment and still meet my system design requirements. But at no point did -- having 4,000 megabits per second go to the end user come up in that discussion. I thought that was fairly interesting.

It's a good lead in to segment 2 because now we get to talk a little bit about the characteristics of the systems that are out there, the technologies that are out there. We know what some of the driving forces were in coming up with those, but what exactly are the capabilities? We heard some of the processing speeds, what we expect in the next couple years that we'll see at Circuit

City, for example. But I'd like to focus a little bit more on how to deal with interference specifically. For example, are there techniques being used out there in the radio communication systems that bring uniformity to signal wave forms. And to distribute the power a little more efficiently and we heard a little bit about the cosecant squared antenna. We can maybe bring that a little bit further.

But taking that perhaps a step further, and looking at the intelligence built into the system in dealing with self-interference and whether or not there's any intelligence in systems today and whether we anticipate there to be in the next couple of years or 10 years out for there to be a way for these systems to detect who's around them causing them interference, causing your system interference and how we would anticipate dealing with that from a system design and try to mix things up a little bit here. Perhaps we'll start with Ray at this time and work our way towards the center of the panel.

DR. PICKHOLTZ: Yes, I think certainly that's true. I just want to make a comment that there have been lots of improvements in the last 10 years. I'll call them naive improvements, things like better filters, beam-forming antennas, Qualcomm's CDMA 1S95. They are naive improvements because they do not extract all the possibilities that are there.

Now just sticking with cellular, there's 3G coming up. I don't know if 3G will ever survive. Maybe it will be 4G before 3G comes, third generation. But many of the people who are serious about 3G, especially in the Far East, have actually built systems with more than simply a multi-sector antenna with a very large number of sectors and narrow beams. And more than simply having adaptive filters and adaptive power control, but actually have included some of things I mentioned before, namely true multi-user detectors, that is to say, they're fairly sophisticated devices that recognize that there is a priori knowledge that you can use to help you overcome the environment that you and your partners sharing the spectrum are actually causing. It's not as if it was totally unpredictable Gaussian noise. And to the extent that you can take advantage of that, and you can, the technology keeps moving. There are much better building blocks now. We talked a little bit about making software radios. In principle, at least, you can make software radios so that standards and weight forms don't count. You just transmit the number of the particular standard of thousands that are stored in a RAM somewhere and the algorithm for decoding it is right there. So that's in principle. I don't know of anybody who is building that in practice, especially over multi-broad bands. There's, of course, a semiconductor revolution, advanced signal processing, but last but not least, a very deep understanding of the limits of communications. I'm talking about communication theory, that is, what is possible to do and what's not possible to do. How far can you go and how far can you actually -- how close to the limits can you get and it's remarkable that many of the systems that have been simulated and in some cases put in a laboratory environment, have gotten within a fraction of the dB of the theoretically possible. And I'm not just talking about Shannon. I'm talking about space-time coding which offers the possibility of literally growing spectrum where none existed before, multiplier factors. You know, you have 10 megahertz of spectrum, over 100 megahertz and suddenly it's not 100 megahertz, it's several gigahertz of spectrum because you can re-use it again and it's not simply the naive approach of using space by very narrow antenna beams.

So those are the kinds of things that are there. The technology is there because of the signal processing capabilities, because of semi-conductor advances and so on.

And I just want to make another comment. There are some constraints. I've heard them this morning. There are people who, for example, represent the public safety use of spectrum. And as soon as you say "public safety"