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Visions of the 21st Century Communications: Is the Shortage of Radio Spectrum for Broadband Networks of the Future a Self Made Problem?

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INTRODUCTION

John McQuillan:

I would like to introduce you to our next session which I consider to be one of the real highlights of the Conference: our Keynote Presentation:

Visions of the 21st Century Communications

Many of us are wondering what is the role for ATM in the next decade and beyond. It's not far away now, and one of the questions we haven't talked about at this Conference, that we want to focus on now, is wireless and whether the spectrum for wireless is really the scarce resource that many of us have been familiar with all our lives or whether it's really an abundant one.

One of the great challenges for the 21st Century, I believe, is to get all the power of broadband networking that we've been talking about, and, at the same time have the convenience and flexibility of wireless communications. This would indeed be the grand unification. ATM isn't the grand unification - - it's wireless ATM that is the grand unification. And what will it take to bring ATM into the home?

Well I'm really delighted to be able to introduce to you this morning's Keynote presenter, Paul Baran, Chairman of Com21, a company that was formed by Paul to work on 21st Century communications.

Paul is a really notable entrepreneur, inventor and visionary. Paul has started many successful companies and made many important inventions in this industry. Among the many companies he's started and he currently is a director I'd like to mention is Metricom. Metricom is a packet radio public company that offers wireless packet radio communication for personal computers and has got fairly widespread installation now in California.

But to make perhaps a more personal introduction for a moment, I did my Ph.D. work in Adaptive Routing Algorithms at Harvard twenty years ago. I did my Ph.D. in 1974. At the time I tried to read everything I could about what had been done in packet networking up until that point and I came across Paul Baran's work at RAND Corporation ten years previous in 1964.

When Paul sat down, and I don't know how he did this, but he wrote a series of ten reports describing, analyzing and predicting packet switches, based on hardware, adaptive routing algorithms, wireless links between them and really conceived of the whole way that we're planning to build hardware ATM based systems today. So, Paul sees things before other do.

You know, in fact, one tries to describe people by their time constant. Some people think one day at a time. Some people are good at planning month by month or year by year. You know you can't ask someone to do a three year plan in a business if they're a one week kind of a person. You can think of running the military: You've got to have a day at a time foot soldier; you've got to have your logistics people be people who can plan a little bit longer; and then the generals who are planning the theaters of operation have got to be able to see out a year or two.

Well, I've never met anybody with a longer time constant and a more accurate record than Paul Baran... Paul!

PAUL BARAN:

Thank you John!

John entitled this talk Visions of the 21st Century. I am humbled trying to do justice to such an over-reaching title. I am reminded of that Wausau Insurance Company TV commercial. An efficiency expert is introduced who is supposed to give a detailed presentation on insurance recommendations. This guy gets up to the podium and says one word, "Wausau". Then he walks off the stage to an awkward silence, until the audience presumably gets the point.

I have to confess that I am tempted to say the three magical letters, ATM (Asynchronous Transfer Mode) and then sit down. ATM pretty well defines where the higher level protocol portion of the network evolution is going in the future. At least in the mind of some of we ATM techno-bigots.

Having covered so much ground so quickly, there is another part of the network that deserves discussion in the remaining time. That is the physical media itself.

PHYSICAL MEDIA

We have only a limited number of terrestrial transmission media to consider. Really, only four. For the metropolitan network, the cable TV network appears to be the winner, using a combination of fiber at the top of the tree networks, while the tails are coaxial drop cables to houses and businesses. This two-way path provides a lower cost transmission pipe to the home than twisted copper pairs and can even support telephony at a lower cost than in place twisted pairs. This is the position announced by Pac Tel in California. Thus, we expect to see both the telephone and TV cable companies competing using essentially the same technology.

It is amusing to note that while Ethernet moves from coax to twisted pair at 100Mb/s, just the opposite direction of evolution may be occurring in the telco competition from twisted pair to coax.

When it comes to transmission over distances greater than about a kilometer, fiber is the clear winner. And the capabilities of fiber suggest continuing significant cost declines and capability increases over time in terms of $/bit-kilometer.

ON WIRELESS

The last medium that I want to talk about is wireless. Wireless has a major potential role to play in the last 100 meters of network systems by allowing rapid easy interconnection without a jumble of wires. Wireless can allow the user to separate the terminal for maximum convenience and effectiveness. The thick umbilical cords providing today's lifeline connection between the computer and the network could be eliminated

This morning I would like to discuss an issue that limits this possibility of our next generation networks. In brief, I am going to talk about a communications policy issue that will determine what we can, and won't be able to do with our emerging networks of the future. Our particular concern is that well meaning government administrators, responsible for control of the radio spectrum space, are making seemingly innocent decisions that could have disastrous unforeseen consequences. It could even cause our networks of the future to be unnecessarily expensive and less capable than if a wider appreciation of what's really happening was better understood. Of course, any negative consequences of such a result are totally at variance with the objectives sought by those responsible for telecommunication policy. What appears to be missing from the deliberations is an understanding of some basic technological issues.

THE SHORTAGE

The key point at issue that we will question is the widespread belief that we don't have enough radio spectrum to go around. This is a common, fundamental belief. Since we live in a world of scarcity or natural resources it is almost automatic that we believe that there is a shortage of frequencies. This particular resource is somewhat different.

This morning, let's start by reviewing this presumption of a permanent shortage. Let's consider how, with an application of already known technology, we could create even a surplus of frequencies. What may be going on is an inadvertent shortage created by a regulatory structure which has yet to appreciate the potential capabilities of the new digital signal processing technology as applied to communications.

A LINK IS NOT A SYSTEM

When we talk about radio or wireless in the following, we should appreciate that no single communications medium is ideal in every situations, so we build communication networks by choosing the combination of various media links, optimized as a network. If our link requirement is for long distance transmission, then fiber optics tends to be ideal. If it is for distribution of signals to many users located only hundreds of meters apart from one another, then coax cable or twisted pair is the preferred medium, depending on the data rates. And, in the future when we deal with increasing numbers of users, wireless could in turn become the preferred medium, particularly for the network tails in an increasing number of instances. Conceptually this remove the constraints of being like the dog whose freedom of action is limited by the length of his leash.

A PARADOX

Of course any suggestion that there is no real shortage of UHF spectrum is at variance with the common wisdom. But, tune a spectrum analyzer across the band of UHF frequencies, and you will encounter a few strong signals, while most of the band at any instant is primarily silence, or very weak signals. (My words this morning are focused on the UHF range, that's the frequencies from 300 to 3,000 megahertz -- the most valuable part of the radio spectrum for communications with high data rate local data devices.)

The spectrum analyzer connected to an antenna shows that much of the radio band is empty almost all the time! This spectrum is theoretically available for sending a signal if we were to take measurements and know exactly when and where to send the signal. The frequency shortage is caused in part by thinking in terms of dumb transmitters and dumb receivers. With smart electronics, even occupied frequencies can be used. To the modern communications engineer lack of strong signals anywhere, no matter how distributed, represents theoretically unused capacity. This

is capacity that could be utilized with the proper signal processing. With advanced signal processing techniques, any signal below the peak received signal represents potential usable transmission capacity. But, there is a catch. the assumption is that we are dealing with digital signals able to operate with very low signal to noise ratios. That means if a signal is slightly stronger than another that it can theoretically be received without error. (This game doesn't work with old fashioned analog modulation signals, such as high quality analog TV signals where interference even 40 dB below the picture is visible.) [40dB is a power ratio of 10,000. one part of interference to 10,000 parts of signal is visible. Communications systems can be built with 10dB ratio, or 1000 times less vulnerable to visible interference.] You can think in terms of a curve of energy versus frequency. A potentially available bandwidth curve can be visualized by inverting this received energy versus frequency curve and then adding a separation energy band level equal to the requisite signal to noise ratio. This suggests potential spectrum that can be reused by choosing the right form of modulation. This is why you need pristine pure channels for analog transmission like TV, but can get away with a dirtier digital channel . Digital transmission when properly done allows a small signal to noise ratio to be used successfully to retrieve an error free signal. And, never forget, any transmission capacity not used is wasted forever, like water over the dam. Not using such techniques represent lost opportunity.

TABOO FREQUENCIES

Another thing that you will see with your spectrum analyzer is that there is a lot of unused TV spectrum, even in the big cities. As you tune across the UHF TV band and there are big holes and these are called "taboo channels" intentionally left unoccupied because of the limitations of the early era television receivers. You may have wondered about these big black holes, particularly since we now know how to build far better cheap TV receivers than when this early rule was adopted. So leaving all this wonderful spectrum space unused seems to be wasteful, particularly when we know how to use better technology so that more of it is usable. Again, any spectrum space not being used is water over the dam - - and forever wasted.

SPREAD SPECTRUM

Today, spread spectrum modulation approaches can allow many more users to share a common band of channels. This means spreading the transmitted energy over a large number of frequencies and living with more interference. But, there is a regulatory lag in allowing such technology, such as spread spectrum, because it seems to require more spectrum space, albeit commonly shared among many users. The idea of preferring to use signals that take up more bandwidth is at variance with the mind set of most regulators, whose objective has always in the past been to minimize the occupied bandwidth.

NEGROPONTE'S SUGGESTION

We can save a vast amount of bandwidth by at least starting to off load applications that hog bandwidth and that could be better served by using alternative media. For example, TV cable now passes about 96% of the US households and could allow many more TV channels to be delivered to the home than can be supported over the air and could release a vast amount of spectrum space. The use of TV cable started primarily in the US and is also now rapidly growing internationally. Professor Negroponte of MIT oft quoted half facetious words to the effect that the way to solve this problem is 'that everything now sent by radio should be sent over wires and everything now sent by wire should be sent by radio' does have some merit. And the transfer need not be 100%. Shorter range rf transceivers connected to fiber could produce a significant improvement - - tremendous improvement, really. Let's talk about the ...

EVOLUTION TO DIGITAL

Digital modulation is the key. It is far more bandwidth efficient than today's analog modulation. Digital modulation in lieu of the present analog modulation allows ten times as many TV signals to be sent over an existing TV cable and of better quality. If a TV cable carries 50 analog channels, then the same cable would now carry 500 channels. The 500 channel digital TV cable systems are in early manufacturing stage today. The demand for this capability is not to present 500 different channels of TV, but rather to allow the transmission of pay-per-view movies with multiple start-times to make them more attractive to potential viewers. So, the same program would start on the hour, thirty minutes after the hour, on the next hour... so when you come in, you would be able to see a movie right from the beginning.

RANGE REDUCTION

Another direction that promises great improvement in bandwidth efficiency is in the reduction of the transmitted power. In the UHF band the number of geographically dispersed users that can be simultaneously accommodated in a fixed spectrum space varies as the inverse square of distance. Cut the range in half, and the number of users that can be supported is doubled. Cut the range by a factor of ten, and 100 times as many users can be served. Reduce the power further, and essentially any number of users can be fit into the exact same spectrum space presently tied up supporting a few longer distance users. Thus, a mixture of terrestrial links plus shorter range radio links has the effect of increasing by orders and orders of magnitude the amount of frequency spectrum that can be made available. We speak of inverse square ranges. While true for free space signals, when it comes to the real world, the payoff is even more dramatic. For example, radio signal attenuation within concrete office buildings, such as a building like this one we are in now is closer to the inverse 4'th power of the transmitted power. Given the attenuation encountered in these type of buildings means that increasing

radiated power doesn't buy much in the way of range, anyway. By authorizing high power to support a few users to reach slightly longer distances we deprive ourselves of the opportunity to serve the many.

Now, how realistic is it to reduce the range of transmission for the relatively few to allow a greater number to benefit? Consider today's millions of short range cordless telephones, all sharing a minuscule slice of the radio spectrum, while a small number of licensed users hog most of the spectrum. Most of these long range devices could be served by using shorter range radios plus fiber to provide the longer distances sought. Of course, the resulting path is not all wireless, but neither is today's cellular systems. The advantage of tetherless operation is retained for the user's convenience, so that there is very little "give up" here. There is no shortage of TV coaxial cable nor of telephone line capacity to provide the wired medium portion of the pair. Assuming that we did move in this direction, we could then create a vast new radio communications capability to allow the support of a far greater number of users and with greater bandwidths than possible with today's present day regulatory constraints.

SMART TRANSMITTERS

A key technology in our new tool bag that should be mentioned is the microcontroller that allows creating cost effective smart transmitters and smart receivers. For example, a smart transmitter can first listen and then automatically choose those frequencies that avoid the other signals in the band. Think of it as just being a matter of being a good neighbor. The smart transmitter reduces its power level to just that needed to produce an error free signal and no greater. You don't require that pristine pure slice of spectrum to have error-free performance. Digital logic in the chip supports error correcting codes to convert a small amount of redundancy in transmission, allowing corrupted signals to be cleaned up to emerge error free.

SOME KINDERGARTEN RULES

To take the fullest advantage of our new technology with its sharing of a common resource requires that our smart transmitters and receivers cooperate. This may sound complicated, but the rules to make maximum effective use of the shared band are simple -- primarily a matter of common decency in sharing resources. The rules are somewhat similar to those you learned in kindergarten, assuming you lived in a tough neighborhood.

Rule #1. Keep away from the big bullies in the playground. (Avoid the strongest signals.)

Rule #2. Share your toys. (Minimize your transmitted power. Use the shortest hop distances feasible. Minimize average power density per Hertz.)

Rule #3. If you have nothing to say, keep quiet.

Rule #4. Don't pick on the big kids. (Don't step on strong signals. You're going to get clobbered.)

Rule #5. If you feel you absolutely must beat up somebody, be sure to pick someone smaller than yourself. (Now this is a less obvious one, as weak signals represent far away transmissions; so your signals will likely be attenuated the same amount in the reverse direction and probably not cause significant interference.)

Rule #6. Don't get too close to your neighbor. Even the weakest signals are very strong when they are shouted in your ear.

Rule #7. Lastly, don't be a cry baby. (If you insist on using obsolete technology that is highly sensitive to interfering signals, don't expect much sympathy when you complain about interfering signals in a shared band.)

That about summarizes that subject other than to note that this isn't the way we presently handle frequency assignments.

REGULATORY HISTORY

The hang-up here today is that our highly institutionalized regulatory structures contain implicit assumptions about technology that once were true; less so today, and probably not at all tomorrow. The regulatory game is run by lawyers, while the issues are primarily technical. Lawyers tend to view the frequency similar to a piece of real estate. If I owned a frequency, then you can't use my frequency. It's mine, all mine. Frequencies today are treated as a property right. Yet, communications engineers know that statistical averaging of larger blocks of frequencies allow far better usage. That's something we all know about. This is the heart of the concept of sharing an ATM network. We all win as each shared user encounters far better economics than if we had to dedicate a separate network to each group of users. We did that in the old days. This concept of sharing is what cellular radio is all about. Of course we finally did get cellular, but over a decade was wasted because of the regulatory lag between the time that technology was feasible until the time that it was implemented. In fairness, newer thinking is increasingly being incorporated in our regulatory decisions. But, from the point of view of a technologist, the process is agonizingly slow. I think we can do better.

WHERE WE ARE

Today the pioneer who proposes to use the radio spectrum in any truly innovative way faces a bureaucratic hoop jumping game, interrupted with interminable delays. Underneath it all is the implicit assumption that there is a God given shortage of frequencies. That being so, the government must dole out the slivers with great care. It does so using a set of rules based on concepts inherited from an earlier era, but now cast in administrative laws. The lawyer's real estate model of frequencies is but a zero sum game; while the communications engineer views it as a game where many more can win.

ORIGIN OF THE FREQUENCY SHORTAGE

Lack of frequencies is not a new problem. Next year, radio is going to be 100 years old counting back from the time Marconi, as a teen teenager, ran his first experiments in his back yard. Yes, we got radio as a byproduct of an experimental hobby activity; not as the result of any major corporation's research department. The first experiments in radio were funded by Marconi's mother as his father refused to come across with the pocket change for such foolishness -- at least until the time radio worked. Then, his father became a great supporter -- with an excess of advice.

The issue of spectrum efficiency has been with us right from the outset, starting with the early question, "Would it ever be possible to allow more than one radio transmitter to operate at one time?" Sharing the channel was one of the first challenge to early radio technology development. Ever since the turn of this Century much of the history of radio technology has focused on living within an over-crowded radio spectrum. Given the limitations of past technology, the shortage of preferred frequencies was real. Very real. And, with an excess of potential users, it was mandatory for governments to create the necessary rationing mechanism. National and international regulatory structures evolved, concerned in major measure with the ever present issue of scarcity of bandwidth. And, so it was institutionalized into regulatory policy. And once institutionalized, the basic assumptions that got us there are very rarely ever re-examined. And, when they were, changes tended to occur at glacial speeds. .

CREATING MONOPOLIES

To put things into perspective, let's take a moment to understand how the game was played in the past, leading up to today and consider a likely scenario or two. Early spectrum was acquired by the pioneer user, but with the government use assuming priority. As additional spectrum was awarded, it tended to be granted in response to economic and political power of the applicants. Whatever organization held most power obviously was serving most users. Economists regard regulation as a substitute for competition and preferred its use whenever a natural monopoly exists. Whenever a government issues frequency, it creates a monopoly. Become a regulated monopoly, and the government will keep out your competitors.

TERMINATING MONOPOLIES

When a better technology comes along that allows the feasibility of multiple suppliers, it invalidates the natural monopoly argument. The end of a monopoly is rarely a swift process and it is never painless -- particularly if it were well run and highly profitable. After long running anti-trust battles the US telephone monopoly, AT&T, was in part fractured into seven local area monopolies and competition was permitted in the long distance telephone and data communications field. This was an extremely controversial move at the time, and was met by all sorts of Chicken Little sky falling predictions. The sky didn't fall. Instead we saw a major increase in effectiveness in long distance services, fostered by the new competition. And this was perceived as being so successful by other countries, that similar long distance services are being deregulated throughout the world, even by those nations with a long history of sole governmental control.

DEREGULATION OF THE REST OF THE SYSTEM

The first wave of deregulation was limited to long distance communications, as the technology at the time could only support the deregulation of the long distance carriers. Missing was the technology to make local area competition feasible and permit deregulation of the local carriers. This is now in the process of change. With cable TV now passing almost every house in the US and spreading throughout the world, an alternative and more cost effective channel will soon be in place to support alternative local communications suppliers. The combination of fiber/coaxial cable and perhaps radio appears to be the lowest cost way of providing local communications and even telephony, so the new competition is particularly threatening.

THE MOVE TO DEREGULATION

Pressure to deregulate the local carriers is underway. The local telephone companies and the cable companies are in an unstable truce before the all out war, with cross-merger discussions underway. The fear of loosing one's monopoly is never a pleasant prospect to a company. It means competition and the necessity to increase efficiency; leading to big layoffs of long-term employees, giving up perks and that sort of thing. Every month the newspaper carries articles about another telephone company laying off another 10,000 people to become more efficient. The press has been surprisingly polite in not asking what these tens of thousands of employees were doing prior to the threat of competition.

CREATION OF A NEW MONOPOLY

If you spent all your life working in a monopoly and it is going away, it is understandable that you may want to create another one. But, where? If the technology is going to be a combination of TV cable technology plus radio tails, a monopoly protection defense line might be the regulated spectrum ownership of the tails of the network. Maintenance of the monopoly then hinges on maintenance of a spectrum shortage. Those that "own" today's frequencies face a diminished value of their asset unless the shortage can be maintained.

THE AUCTIONING GAME

An idea evolved, first tried in New Zealand and now in the US, to auction off small portions of the spectrum in response to the unsatisfactory alternative involved in issuing frequencies in the past. The era of granting frequencies as political favors ended with the increased diligence of the press. A substitute mechanism, random drawing, was then tried. This process was also grossly misused, as thousands of applications were filed and the winners sold their licenses to the legitimate users -- who in turn built their monopolies. The overall history of the regulation of the radio spectrum is the sort of thing that tends to give government a bad name when it comes to running a business.

The frequencies being auctioned off today (and there's going to be a big sale of these next month) came partially from a give-up of the frequencies reserved by the military and partially from point to point users who are to be assigned alternative frequencies, and who will receive payment for new equipment in the process. While auctioning might seem to be an answer to an unsolved problem, I believe that it will exacerbate the problem and is more likely to lead to the creation of new monopolies. He with the most up-front money gets to lock up frequencies to create an oligopolistic position with a legal barrier to competitive entry. It can be argued, on the other hand, that enough blocks of frequencies are being auctioned simultaneously to insure competition. But, history has shown that in a capital intensive game, he who comes in second, but with most dollars wins by buying out the early players. Everyone walks away happy. The early license holders get a windfall and the last guy gets to milk the public cow with minimum interference.

Next month an odd combination of formally competitive bedfellows will gather together to jointly buy up big slices of the radio spectrum. The November 7th issue of Time quotes Stahlman, an industry observer, as saying "the behemoths who can afford to bid are the least likely to be innovative." The same article also quotes TCI CEO John Malone as saying in effect, "We are starting a new national telephone company." And, so the seeds of a re-monopolization are being sowed -- all based on the assumption of a shortage of spectrum space.

AN ALTERNATIVE APPROACH

A counter hypothesis that I would like to raise for your consideration this morning is that there is really no real shortage and what we are seeing is a manifestation of a self made problem that would go away if we made better use of our present known technology.

In the words of Pogo, "We have met the enemy, and it is us."

If the present approach is lacking, what might we do differently? If our hypothesis is correct, then there is a potential for a limited amount of spectrum to carry all the traffic imaginable (provided the power and the range of the transmitters is limited), then public policy is better served by moving to an environment of near zero regulation. In such an environment anyone would be allowed to use the spectrum, without the high front-end costs that keep out the true innovators. Of course, the allowable power and power densities would have to be realistically restricted.

CHAOS?

Would this lead to chaos? In my opinion, the answer is, probably not. Consider the many millions of cordless telephones, burglar alarms, wireless house controllers and other appliances that operate within a minuscule portion of the spectrum and with limited interference to one another. These early devices are "dumb devices" compared to equipment being developed able to change the frequencies and minimize radiated power to better avoid interference to themselves and to others. Of course this means that there will have to be enough frequency spectrum set aside to do so. But, once having done so we would have created a communications environment able to handle orders of magnitude more communications today.

AREN'T WE DOING THAT ALREADY?

In the US the FCC has allowed unlicensed operation in the Industrial Scientific and Medical bands These are "garbage bands" -- the home of radar ovens and diathermy machines. Some say "too little and too late." Nevertheless access to the ISM bands has proved to be of tremendous value in the creation of truly innovative major new services -- such as noise free high quality cordless telephones and wireless burglar alarm services. However, a shadow is growing as some in the FCC are proposing chopping up this band even into smaller pieces, and then artificially limiting the use of this band to force users over to the auctioned frequencies to increase the monopoly value of the frequencies being auctioned.

POSTSCRIPT

Now, do we need all the regulation where each slice of frequency in each geographical area is tightly controlled by Washington? Or might we be better off if we used the Internet as our model? No central node. Local decision control with a minimum of restrictions. The Internet is growing rapidly. It is inexpensive and it allows the broadest access to the world's information to a greater number of people than ever initially imagined. Yet, it is theoretically chaotic, as would be sharing a common band of frequencies by all comers. We know that both examples of distributed networks can be made to work.

Nevertheless, today we see our regulators considering slicing up the ISM band. In comparison to successful example of the freewheeling Internet type model that works so remarkably well for huge numbers of users, slicing up this common bank is like a move back to a centralized control reminiscent of the old Soviet economy. And we know so well today, that particular centralized system didn't work all that well.

SUMMARY

So, in conclusion, I'd like to say that the role that wireless can play in the ATM world of the 21st Century is bounded by just two things:

1) the imagination of the system designer, and 2) our ability to explain the implication of the emerging technologies to those responsible for passing out the radio frequencies.

Unless the long range implications are better understood, we could significantly delay the availability of technology of major economic importance.

Thank you!

QUESTIONS (Submitted on cards and selected and read by John McQuillan:)

John McQuillan: Thank you very much Paul, that's real food for thought. It's a little depressing in a way to think that we've wasted so much opportunity already. But, perhaps we can look forward to doing a better job going forward.

We have a couple of questions here from the audience:

One promise of broadcast spectrum that you didn't touch on but that certainly appeals to all of us is that we've tended to think of it as "free" when we turn on our broadcast TV. It doesn't cost us anything and when we do our garage opener, it's free. Isn't that going to present a problem in moving some people out of radio spectrum and onto cable because you have to pay for cable television unlike broadcast television?

Baran: In short, the answer is "yes". But, it's more likely a matter of providing a low tier free coverage for the broadcast channels. It may well be in the cable company's interest to provide free access to solely "over the air" signals. Once the cable is in-house, then the cable operator could sell incremental other services.1 While the answer is "yes", that nobody likes paying for services they can get off the air free. But, the movement in growth of cable is very real and I think its advantage increases with time, so, it is not out of question. This is not something that's going to happen right away, and we don't need 100% penetration everywhere, as the shortage bind is only in the big cities.

McQuillan: Considering where we are in the U.S. with an embedded base of dumb TVs, broadcasting monopolies and the general inertia of our regulatory system, do you think it's possible that your ideas are going to be adopted in other countries before they are in the U.S.? Possibly in some emerging countries in the third world?

Baran: Could be! You know, when you said 21st Century, that covers an awfully long period of time. What can happens over such a long period is hard to imagine. All I can talk about is the trend line. It is hard to pick an exact date and who's going to do what -- particularly when you deal with political type decisions. We can predict technology quite well, but historically it has been found nearly impossible to predict political decisions as they tend to be a function of a single person's whim, rather than the composite result of a large number of

separate actions that all combine together in the case of a technology evolution direction.

McQuillan: Well here's a good question that picks up on one of your very last thoughts. Paul, how can we improve our ability to explain the implication of these emerging technologies to those responsible to handing out spectrum?

Baran: That is my key objective of this discussion this morning. The more people that are aware of the problem, the faster we're going to work our way towards a solution. I think it behooves all of us who are aware of the problem to pass the word around; to study it, to see whether it makes sense to you. And, if it does, then it increases our base of those that appreciate the nature of the game being played. I think when this understanding becomes more widespread, we increase our chances to see some movement over time.

McQuillan: One way of understanding your remarks is to say that there are two themes. One is that there's a revolution in digital technologies, especially digital signal processing, which is going to allow us to completely rethink how we move information through the radio frequencies and the other is that at the same time and for rather different reasons, we're considering the deregulation or re-regulation of these frequencies. Which do you really think is really going to happen first: the large scale use of digital signal processing technology giving us better frequency utilization, or an effective deregulation of the spectrum we are currently using?

Baran: Either of these two directions can allow us to win the game.

If we can make much better use of our existing channel using digital signal processing, then the pressure for saying there's a shortage of frequency goes away. Or, it can be done by smarter regulation. Either way we end up at the same point. So, are many paths - any one of which can get us there. But, all can be blocked by intentionally unwise regulation.

McQuillan: You know, for years I've had the mental model that broadband and wireless were two orthogonal axes and you could get more and more high performance in your network with a better and better wire and better and better switching. Or, you could have more and more convenience and portability in wirelessness if you were willing to accept lighter weight, less power and more primitive devices. So in the one limit, you have the Silicon Graphics work station on fiber getting ATM at the other limit you've got the little pocket pager that just basically delivers one bit saying "you've been paged" and you

carry that everywhere. Isn't it really utopian to suggest that we can just throw away that model and we'll be able to have any communication anywhere?

Baran: The answer is yes, but you can go high data rates very short distances; or lower data rates further distances. Remember that we don't need to build a system using only a single medium. We can use combinations of media. So in this case, it will be radio for just that portion where it's a pain to carry signals by physical wires and then as quickly as possible, move over to a wired medium or fiber or coax and then go the rest of the way by electrons or photons. It is a matter of mixing, combining the two to get the advantage of both and minimize the disadvantage of each.

McQuillan: So the vision of the 21st Century communications might be a hybrid fiber coax or a fiber to the curb arrangement to the business and the home. And then, broadband wireless within the last few hundred meters within the building.

Baran: It could be only a few feet for very high data rate radio devices or a mile or two for low data rate devices such as a PCN telephone.

McQuillan: Paul's too much of a gentleman to go into this, but his company, Com21 is pursuing this vision commercially. Paul has acquired a number of patents in this area and so he's actually putting his money where his ideas are on this point.

Timely subject, we've cleverly planned this conference so that this session and the subsequent one on "Discussion of Washington" seem to happen the day after the elections.....what do you think?

We've got a whole new ball game in Washington now - - all new House and Senate - - Republican controlled. (I'm not going to pause for applause or for any other kinds of comments - this is a non-partisan event.) [LAUGHTER] I'm just asking Paul - - well, what do you think? Does that change your views of how we might be proceeding here?

Baran: No, no. The concept of selling off of the frequencies seems to have political acceptance by both parties, but for different reasons. I think that the Democrats it looks like the new way of raising taxes...

McQuillan: Yes, I noticed that...without using that word!

Baran: ... and to the Republicans, it appears to be a way of

privatizing government assets. So this move is politically acceptable by both those that like raising taxes by stealth, and by those that believe that government has no role here as this is something best left to the marketplace.

McQuillan: So why wait for regulatory change? If signals can sneak in and coexist on the bands, then no one else will really notice when you occupy an unused tiny slice of spectrum in the neighborhood. [LAUGHTER]

But wait, there's more, so start now - - develop a base of important users - - don't worry about the dinosaurs, the mice are fleet afoot and hard to spot in the grass.

Baran: Very good! Great idea!

McQuillan: It's pretty radical!

Baran: We're getting to see some bootleg stations in the FM band. Once upon a time the FCC was very tough about it. But so much of this sort of stuff is going on that they're sort of looking the other way. It could be like marijuana - - where you have tight rules but they don't get enforced. And, after a while the rules become unenforceable. I'd hate to see us move in that direction. I'd prefer to have us face up to the fact that there's a change needed here, and we would much prefer to work within the laws.

But the point you raise is a very good one. There's a heck of a lot of stuff you can do (using the spectrum) without getting caught. [LAUGHTER]

McQuillan: In a way that might be the American way or the free market way: that we the users have to demonstrate with action to the government the right way to go and then they'll regulate almost in hindsight or in afterthought.

Baran: That's right! That's the history of the Internet.

McQuillan: Indeed, yes!

Baran: Chaos up!

McQuillan: Right, and now President Clinton says "I want everybody in the administration to have a mailbox in the Internet". Whereas a few years before that would have been unheard of. Partly because no one knew what it was and partly because everybody thought it was a joke.

It's funny how things can transition from being a joke or being wrong to being the middle of the road accepted idea.

Well in your vision of the future, there are these potentially large number of end stations which contending for spectrum by using spread spectrum technology and by using a lot of very clever electronics, doesn't this end up meaning that the end stations need to be quite expensive to be so smart?

Baran: No! With silicon the complexity is no longer a factor. As long as the numbers are big, and they will be in this case, you can pile an awful lot of capability into a very inexpensive chip or a few chips. And the cost of the chips is pretty much a matter of dividing a fixed cost by a number. If the number is big then the cost per chip can be fairly low.

McQuillan: Do you think that can get so cheap that it can go into telephones?

Baran: Oh, yes!

McQuillan: Putting you on the spot here, do you think we'll see ATM telephones?

Baran Yes!

McQuillan: That's really the end game here isn't it?

Baran Yeah, I could see cells going right down to the telephone instrument itself. We've looked at that one and it seems to make sense.

McQuillan That's the logical conclusion of this line of thinking is that you build fiber to the curb or hybrid fiber coax. You deliver video and data but you're also delivering telephony and then all the devices in the home or the business that televisions and the computer, but also the telephones have to be peers, have to be wireless, so that means they have to have wireless ATM. Thought for the day.

Baran: The ATM cell is the key.

McQuillan: For those of you in the chip business, this is a good thought for the day.

Is the FCC examining this question of the last mile becoming wireless for broadband services for the home?

Baran: I don't know. I don't think that's very high on their agenda. The FCC has a few very good technical people, but they're totally outnumbered by the lawyers. [LAUGHTER]

McQuillan: I'm sorry to hear that, but I'm not at all surprised. I mean, that's what we get in Washington and I don't know, what do we do to change it? You seem to be advocating a kind of a public awareness and education campaign. Is there any reason to believe that would work or do we have any example of that working before?

Baran: Well, it worked yesterday! [LAUGHTER & APPLAUSE]

McQuillan: If only we had direct election of FCC Commissioners that would really be something.

So, I know this is a difficult question, but being an optimist for a moment, when do you think that we might get a significant adoption of your ideas?

Baran: I think that this is one of these multiple S shaped curves.... these things always take a hell of a lot longer than you think they should. Someone pointed out that no truly new communications system ever got from laboratory to full field implementation in less than fifteen years. So we're talking pretty long time constants. But that doesn't mean we can't see some thinks occurring very early. There's the bottom of the pyramid and then we start moving up.

McQuillan: It also doesn't mean that we can't use that insight to be quite clear about what's strategic and what's counter strategic in moving over the next few years. There's a lot of efforts I see as pretty counter strategic to this line of thinking in this whole revolution of cable companies doing telephony and telephone companies doing cable. Clearly, I think one's view of what are the important assets to protect needs to get revised from this prospective that spectrum is abundant rather than scarce and that digital signal processing is one of the key technologies, rather than a, let's say, HDTV being one of the key technologies, you know, in this view, which I share, compression isn't really the issue. While fiber's very important, that's not really the issue either because we've been living with fiber for a long time, but we can't afford to put fiber everywhere. The real issue is, what do you do to get to the user and I think Paul's contribution here is to suggest that we've solved a lot of the other problems but we don't really have a good solution yet for getting all the way to the user and that wireless represents the solution that people aren't thinking of for that.

So, Paul, thank you very much for being with us this morning!

Footnote added after the talk:

Assuming fewer 100 million TV households of which 65% already take cable then fewer than 35 million households would require access to the cable. Cable systems generally are wired for taps for 100% penetration (because they don't know who will and won't take cable.) The missing items is running coax drop cables to the houses without cable. Assuming a cost of about $30 per house in a mass contracted out installation, the total cost would be about $1 Billion to free up over 400 MHz of high quality bandwidth for the entire country. This is about 1/10 the cost of the amount that is expected for the PCS licenses being auctioned off. And, it is only 5% of the $20 Billion annual cable TV revenues. If this approach was limited solely to those few large cities where any semblance of scarcity can be said to exist, the cost would then be correspondingly lower.
