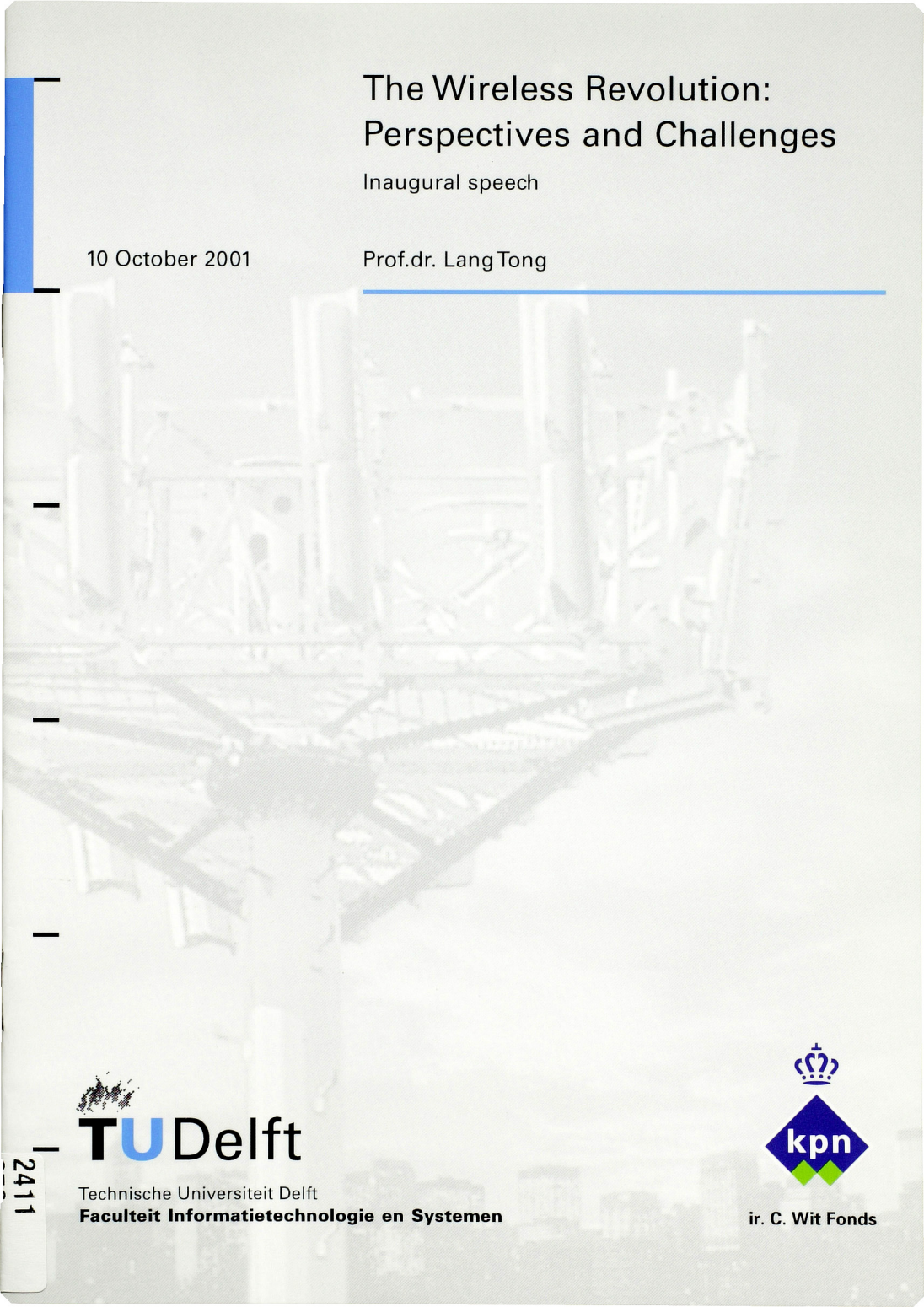
The Wireless Revolution: Perspectives and Challenges

Inaugural speech

10 October 2001

Prof.dr. Lang Tong



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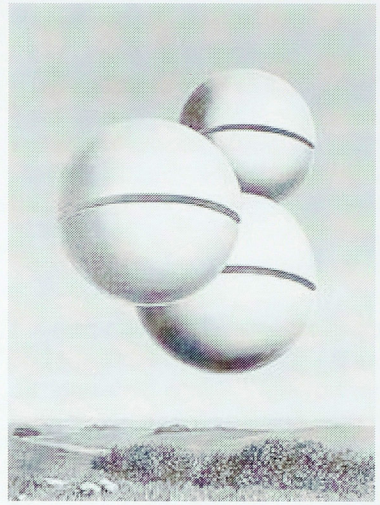

The Wireless Revolution:
Perspectives and Challenges

The Cor Wit Lecture
10 October, 2001

dr Lang Tong
Cor Wit Professor 2001

Cover Image: Voice of the Air. Rene Magritte

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Mijnheer de Rector Magnificus,
Leden van het College van Bestuur,
Members of the Cor Wit Foundation,
Mr. Cor Wit,
Fellow Professors, students and members of the University
Distinguished guests from KPN
Ladies and Gentlemen:

Good afternoon. Thank you all for coming to this lecture.

I like to express my sincere gratitude to the Cor Wit Foundation and the Delft University of Technology for honoring me with this distinguished chair. I like to thank Prof. Patrick Dewilde for hosting me and discussing with me on many topics relating to this lecture. His presence in the class I am teaching here at Delft always keeps me on the edge. I must also thank my good friend Prof. Alle-Jan van der Veen for, among many things, teaching me, so very patiently, the two Dutch sentences that I have just uttered before you.

Had I given this lecture two years ago, in the closing months of the last century, I would have started quite differently. Time was good then. The economy was booming, especially in the telecom sector. A Master Degree student with the magic word "wireless" in the title of his thesis would be sought after aggressively by companies of all sizes, and would probably be offered a salary over 70,000 dollars; a PhD over a hundred thousand dollars. They made their professors look, and feel, like losers.

The end of 1999 was a high time for wireless. The number of people having cellular phones had been growing at a spectacular rate. Those slick digital phones, glowing in the dark, made it embarrassing to carry the sturdy looking but perfectly functioning analog phones. It was a fashion, you got to have it.

The wireless industry had a plan for us. Having tasted the wild success of the 2nd generation wireless, they decided that we all needed the 3rd generation, 3G as they called it. They had been battling on 3G standards since 1992. They now got it all worked out, armed with their own book of acronyms as thick as a dictionary:

UMTS, UTRA, UTRAN
WCDMA
PCH, PCCH, PCCPCH....

The only thing they needed was the right-to-transmit---the 3G licenses. Governments all over the world were excited. Auctions started in earnest. Thirty five billion dollars yielded in Britain, over 46 billions in Germany. These numbers were staggering considering that the previous 30 auctions in US totaled less than 20 billion dollars [1].

In 1999, buying technology stocks was the smart thing to do. If you had $800, you might consider buying a few shares of Lucent. After all, how could a company that invented the idea of cellular go wrong? It was reported that Bell Labs unveiled a new weapon, they called it BLAST. You weren't sure what it was, but it sounded as if it might blast your portfolio into the orbit of unimaginable wealth.

It felt like a dream.

Anxiety

Well, something did go wrong. Your $800 investment in Lucent now values around $60. Had you bought $800 of Heineken, not the stock of the company, but the beer, and you had a New Year party with your friends, returned empty bottles to the supermarket, you would have gotten $240 back.

It turned out that the industry hadn't figured everything out when they invested heavily in 3G. They had not thought about what an ordinary person really wanted. They forgot to check with their customers.

In a survey [2] of 13,058 people in 12 European countries conducted only this year, 90% said they did not know much about 3G. In a scale from 1 to 6 with 1 being the least interested in 3G, the average was 3. Wouldn't it be nice if they had these figures before they emptied their bank account for 3G licenses?

Anxiety Edvard Munch

William Kennard, the former chairman of FCC in charge of spectrum auctions in US, was quoted saying that the 3G auction is for a "prime beachfront property" [1]. Well, if it is a prime beachfront property, we should expect a magnificent house with huge windows facing the ocean. But the planned 3G services

resemble a little hut with a window that can hardly fit the sight of a full moon.

Worse still, many companies have little money left to build even a hut. It is like spending all your money at the door of a club and having no money left to buy a drink, or renting a fabulous apartment in Amsterdam but having to live on one meal a day. The other two meals are laid off.

How you wish that this were just a bad dream.

To prepare this talk, I went to the library at Cornell looking for whether, at an earlier time, someone had given a similar type of lecture. Perhaps I could steal a few ideas and find something inspiring to say at a troubled time of our field. I found an old booklet [3] by James Harbord who gave the Brackett lecture at the Princeton University on November 12, 1935, nearly 66 years ago. The title was: World Wireless: The Engineer's Place in Radio Communication.

Mr. Harbord, a retired US Army General, was first the President then the Chairman of the Board of RCA, a company at the cutting edge of wireless at the time. Let me quote a few things he said in his lecture:

> "The ultimate achievement of communication will come when we, at last, can see the man who is talking to us even though he is in a distant city, when we can watch every change of his expression, catch every tone of his voice."

He then went on to say:

> Teachers of foreign languages have often used as a horrible example for their classes the awkward translation---"He took the little boy apart and talked to him." Communication by television,

> breaking the images of speaker up to infinitesimal parts and reassembling it, will go even better. Then we can say---"He took the little boy apart, put him back together again miles away, and talked to him"

Considering that the speech was given in 1935, one must admire Mr. Harbord's foresight of digitally video phone.

Fig. 1. Cartoon which appeared in the December issue of the Punch Magazine in 1879 [5].

A 19th Century Dream

The idea of having both voice and video in long distance communications is of course not the invention of Mr. Harbord. Shown in Fig. 1 is a cartoon appeared in the December issue of Punch Magazine in 1879, the artist depicted the use of video-phone between UK and Australia. The caption said: every evening, before going to bed, they set up an electric camera-obscura over their bedroom mantel-piece, and gladden their

eyes with the sight of their children at the antipodes, and converse gaily with them through the wire.

I ask you to pay attention to the setting. The old couple sat comfortably in front of a gigantic TV, much like the High Definition TV advertised today. The telephone had been invented just 3 years before, and they would have to wait for another 74 years, in December 1953, before the NTSC standard on color TV was adopted. Today, over one hundred and twenty years later, you can purchase everything in this drawing at a reasonable price, but you can not have the service shown in this picture. Nor can Mr. Heineken, perhaps the wealthiest person in the Netherlands, not even Bill Gates, the richest in the world.

How can someone miss such a market that may have millions of willing customers?

Fig. 2. The 1970's Picture by AT&T

The 1970's Experiment

The first video phone system was built in 1956. By 1964, the public was invited to place calls using Picturephones between

special exhibits at Disneyland and the New York World's Fair. Commercial services debuted in 1970 in downtown Pittsburgh, and AT&T executives confidently predicted that a million Picturephone sets would be in use by 1980.

Depicted in Fig. 2 is the 70's model. I again ask you to pay attention to the setting. A secretary dressed formally in a business suit looking into the camera as her boss is looking at her from a small black-and-white TV screen. Both look quite serious, neither seems to enjoy the experience.

The 1970 experiment with video phone was an utter failure, and the reason of that was more than technical. Robert W. Lucky wrote in his book [4], *Silicon Dreams: Information, Man, and Machine,* that Picturephone was too intrusive. Using it, "you have to stare stupidly into the camera" all the time, and you don't want to be caught not paying attention, especially when the other side is someone important but not necessarily someone you like (your boss, for example). Ask yourself how many times you are on the phone and surfing the web at the same time.

While communications are essential, people seem to need a buffer, especially in business dealings. For telephone, that buffer is not to be seen. For email, the buffer is not to respond instantly, or even the option of not to respond at all.

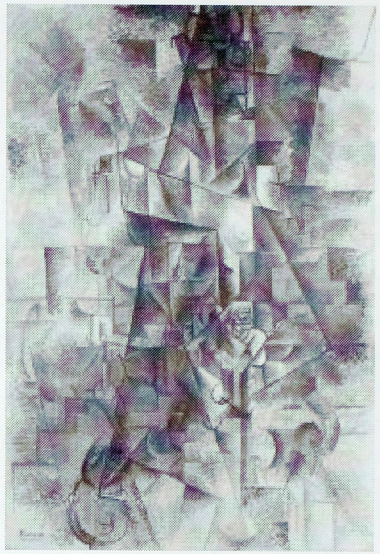
Accordionist

The failure of 1970 did not kill the idea of video phone. Today, you can buy a high-end video conferencing equipment with a large color TV screen, targeted for large businesses, with the data rate up to 3 megabits per second at broadcast quality for a hefty price of $49,000. Haven't we learned that people are reluctant, even hate, to use video conferencing? The $49,000 price tag is clearly not for an ordinary family.

Meanwhile, much attention has been paid to the internet with numerous companies selling low-end devices so that you can see someone via the net, free of charge. It is an inexpensive technique without assurance of quality. By design, the internet is not the perfect medium for communications with strict quality standards. So the pictures are often jumpy, and the delay in voice intolerable.

If you talk to Sir Issac Newton using the Microsoft NetMeeting over a telephone line linked to the distant past, you would see puzzlement in his eyes when he saw, on the tiny window of his PC, that your head had just moved half a meter in no time, contrary to all the laws he knew by heart. When you were about to ask him what went wrong, Sir Newton's head on your screen decomposed into blobs of squares as in Picasso's "Accordionist." This is exaggerated, of course, but you get the idea that today's video communication over the internet is nowhere close to what was depicted in the Punch magazine a hundred and twenty years ago.

It does not seem to bring us closer in distance. It reminds us of the distance.



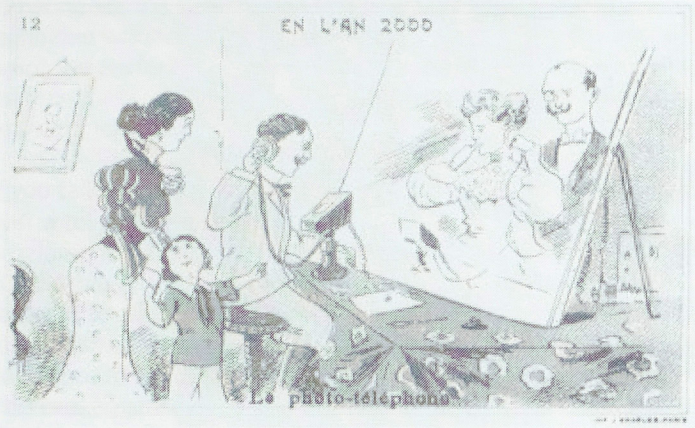
Accordionist (Pablo Picasso)

A Failed Prediction

There are a lot of predictions about technology that are so timid that we laugh about them today. You probably have heard that Thomas Watson, the founder of IBM, predicted that the whole world needed about five computers. Most likely, he was thinking that all of them should be made by IBM.

But this 19 century prediction shown in Fig. 3 about year 2000 is by no means timid. We have already failed that challenge. Like the previous drawing, this again was about a video phone used on a family occasion. The woman in the big screen TV was showing off her new hair-do, perhaps also the new dress. The screen resolution must be incredibly high as they sit so close to

it. Why is this prediction about year 2000 wrong? Many can afford a big screen TV, and video cameras priced from $20 to over $2000 are now readily available.



A nineteenth-century prediction of the state of the art in the year 2000.

Fig. 3. A 19th century French prediction for the year 2000 [5]

Is the cost of transmission prohibitive? Hardly so. Let us do some calculations. I calculated that for a broadcast quality video (at the rate of 3Mbps), you will have to pay a rate of four dollar and seventy cents per minute assuming that a one minute use of telephone line costs 10 cents.

This is a little expensive, but I bet quite a few would be willing to pay for it on special occasions: to see the new born of your nephew, to talk to your fiancé who happens to be away, to comfort an elderly confined in a hospital bed, or to show your parents the diploma you have just received. The first trans-Atlantic phone service cost 5 Pounds per minute in 1927. At the 4% inflation rate, it would be over $130 in today's money. Comparing with that, $4.40 is not that bad.

But you rarely need the broadcast quality video, and there are many compression algorithms that can reduce the rate further. Some say that 1.5 Mbps is already sufficient unless you are trained to detect artifacts caused by compression. That cuts the cost by half. In US, we are inundated by sales calls from telephone companies, offering you 5 cents per minute if you sign up with some calling plan. That makes it a dollar and twenty cents per minute high-quality video, on a big screen TV, in the comfort of your home. I am willing to pay that amount to see the piano recital of my son and for my family to watch this inaugural speech.

If it is not the cost, is it the technology? I think the technology is already in place for providing high quality videophone services targeted not for businesses, but for high-end users who are willing to pay.

Two things must happen. At the network level, the telephone company must be ready to provide such services; they must grab data from videophone and pass them through the circuit-switched network where there is a strict quality of service guarantee. Next, we must have broadband access. That means beyond 3G. I will make a case that wireless devices, some already on sale for less than $200, can realize what must have been considered an artist's fantasy over a century ago.

The Two Remarkable Prophets

Before I make this case at the technical level, let me tell you about two remarkable prophets who played immense roles in shaping the telecom industry.

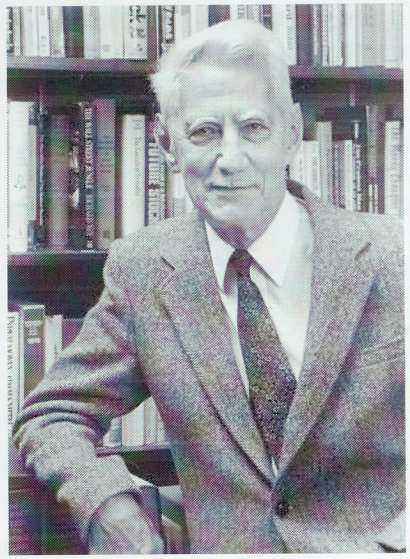


Fig. 4. Claude E. Shannon (1916-2001)

The first is Claude E. Shannon who died earlier this year. The law of Shannon attaches a number called capacity to the communication channel. It says that you can have a virtually error-free transmission if your transmission rate does not exceed the capacity. The fact that the capacity can be greater than zero was as astounding in 1948 when the theory was first introduced as it is now.

So what that magic number? Is the capacity so small that those 19th century predictions were merely fantasies?

In the June issue of Nature [6] this year, it was reported that a single strand of optical fiber has a capacity of 100 terabits per second, that is 100,000,000,000 bits per second, or over 50,000 broadcast quality videos transmitting at the same time, over the same optical fiber. This is a hundred times more than all the

traffic loads in of the world's communications networks put together in 1996. How many fiber strands are there? It is reported that US companies have been laying 4000 miles optical fibers every day for many years. So what is the worry about not having enough capacity? One should worry about not having enough people using and paying for the capacity. Some say that over 60% of optical fibers are not in use. No wonder the stock price of Corning, one of the leading companies making fiber optics, dropped like a stone from a $107 per share to $8.

How about wireless? The calculation of the capacity of a wireless channel is a serious science. In general, we don't really know the capacity of a particular channel. If you make reasonable assumptions such as Rayleigh fading, you find that the 2G GSM channel with 200KHz bandwidth can carry about 1.1 Mbps at the signal-to-noise ratio (SNR) of 20dB. But that rate needs to be shared by a number of users, say, 8 in the 2G system, which gives you 140Kbps, not enough for broadcast video. What about that expensive 3G spectrum we have just leased? The bandwidth allocated for 3G is 5 MHz per RF channel, which is 25 times wider than the 2G system. Now we are in business.

So the capacity is abundant. The next question is how to design systems that realize the capacity. Like a true prophet, Shannon pointed out that, at the end of the rainbow, there is a pot of gold, and there is a road leading to it. When asked for a map, he smiled and gave no answer. Finding the road is supposed to be the job of mortals. But here lies one of the most remarkable triumphs in the telecom history. According to Shannon's theory, the capacity of the telephone channel is about 58Kbps. For less then $60, you can buy a credit card size modem that gives you 56Kbps plus all kinds of features that you probably will never use. The capacity is achieved for all practical purposes.

Reaching capacity requires deep mathematics, enormous computation, and ingenious engineering. What makes it possible has a lot to do with the second prophet, Gordon Moore of Intel.

In 1965, he gave what is widely known as the Moore's law: the number of transistors per integrated circuit doubles every 18 months. Put it in another way, you can compute twice as fast as you could a year and half ago, or the size of the same device is halved during that period. While this has been true since the birth of integrated circuits, remarkable for sure, the Moore's law is not a law to be held until eternity; it will fail someday in the future, and many are betting, some are praying, that it won't fail for many years to come.

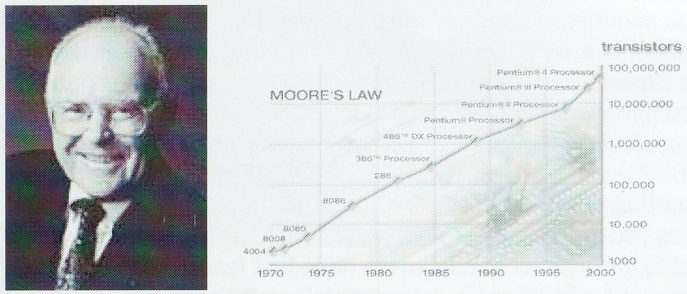


Fig. 5. Gordon Moore and his Moore's Law

What is less publicized, I think, is the psychological impact of Moore's law on engineers and their managers. It makes them much more willing to consider techniques beyond their current capability. It cuts the invisible shackle that fetters the creative mind. As a result, many remarkable techniques were discovered and eventually made their way to actual implementations. The telephone modem you have now is the result of the relentless pursue in universities and laboratories all over the world by engineers, graduate students and their professors, often using Moore's Law as the excuse of pushing a complicated idea forward.

If one believes that the capacity of the 3G spectrum, even some fractions of it, can be reached in the future, one should have no

doubt about the future of Broadcast Quality Video Services. Call it BQVS, the next killer application.

All those Gs

1G, 2G, 2.5G, 3G, and 4G.

I was interviewed by a few Dutch reporters on topics relating to this lecture and about wireless in general. One by one, they asked me: what do you think about 4G? Apparently, they had the impression that I am an "expert" of 4G, which is as big an exaggeration as the Rokkostuum I am wearing now.

1G stands for the first generation analog cellular introduced in the 80s. Most of Europe used the system called NMT-450 or NMT-900. In US, it was the AMPS. France had one all by herself with a forward-looking name. It is called Radiocom 2000. (Perhaps 2000 means the time when the system will be turned off.)

The idea of cellular was introduced in the 70s, and it was revolutionary. It divides the world into cells, and each cell has a base station behaving like a powerful warlord within his territory. He handles all communications, and collects taxes from everyone. When you want to say something to your friend sitting next to you, you talk loudly so that Mr. Basestation, the local warlord, can hear you. He then repeats your message to your friend, loud and clear. It sounds ridiculous, inefficient, and awkward, but that is how all cellular systems work.

2G was introduced in the 90s, and it is digital. It handles more calls and it has more levels of hierarchy as micro-, and picocells were introduced. The warlords now delegate some of their jobs to micro- and pico-warlords. As successful as GSM and other 2G systems are, the technology used in 2G was hardly revolutionary.

2.5G came to scene in the last few years. The hierarchical structure does not change. Warlords continue to rule with sharper knifes and more powerful bows and arrows. It pushes the technology of 2G further, introducing more sophisticated protocols and modulations. It aims to provide 115Kbps and up to 384Kbps.

For 3G, the spectrum is increased to 5MHz per RF channel. It offers the data rate of 144-384 Kbps and may be more, especially when you are the only one in the cell. You may get 2Mbps. Emails and other data services are part of the deal. The warlords are anxious to get more cash to pay for their new gears. Heavy taxes are to be levied on you.

What about 4G? I had an impression that no one knows what it is. Perhaps people are not so happy with what 3G promises and start to dream about something better ahead. To me, 4G should be something that 1-3Gs are not. How about getting rid of the warlords for a change? How about some democracy? Let me describe one technology that, I believe, will be part of the next generation and beyond. It is the wireless LAN.

Wireless LAN

Unlike 3G, the Wireless LAN technology is already in your neighborhood electronic store, and it delivers 2-11 Mbps, a rate more than adequate for broadcast quality video services. New devices offering 58Mbps are in the pipeline. For a little over $100, you can get the wireless LAN card of the size of your credit card. Plug it into your laptop, and you are connected. It operates in the so-called ISM (industrial, scientific and medical) band that does not require a license provided that you don't transmit with too much power. Free lunch? Not exactly, and I will talk about where the hidden cost is, but this sure beats paying billions of dollars just for the right to transmit. This is the

reason that this technology is already here, and is going to bloom like wild flowers, tulips in the spring time.

What is really interesting is how you are connected to others via wireless LAN. It has two modes. The first is the peer-to-peer connection, shown in Fig. 6 (left), or the so-called ad hoc networking. You connect with other nodes directly, just like how people talk to each other in outdoor cafes in downtown Delft or on the beach in a Sunday afternoon. Tax collecting warlords are gone.

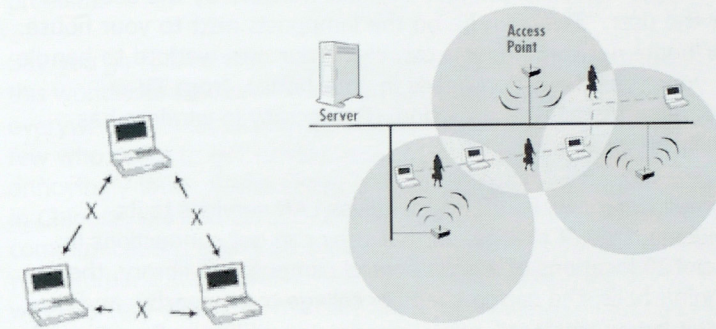


Fig. 6. Left: The ad hoc mode. Right: The infrastructure mode.

You can see immediately how useful this mode of communication is. Real-time games, group projects, and individualized instruction in classrooms. One realizes that this is exactly how computer networks were initially formed. Nodes were connected, one by one, with no centralized control. The result was that the network multiplied and continues to multiple by itself. Interestingly, like the internet, the idea of ad hoc networking also came from a DARPA project in the 80s. It was called packet radios. I think that it will grow like the internet grew, and you will find a much wider use of ad hoc networking in the next generation of wireless.

The second mode of connection is the infrastructure mode shown in Fig. 6 (right). Here is where high quality video can be transmitted across the network (provided that the telephone company is willing to modify their access protocols). Each node can associate with an access point connected to the high speed network. You may think the access point is like the base station, the local warlord. To some extent you are right; he does handle all the local traffic. But the differences are that these access points cost less than $200 a piece, and they don't collect taxes from you. They are plugged into the network by the user and for the user. They can be on the lampposts next to your house. For home networking, you can elect your own warlord to handle all your communication needs in your house, from TV programming to web browsing. Democracy in wireless has finally arrived!

Cornell University is offering wireless LAN services to its students, free of charge, so that they can get connections in over 120 locations of a wide spread campus, the library, the dinning halls, the coffee shops in college town nearby, and the green lawns scattered among academic buildings. Ezra Cornell funded the University in 1868 at the dawn of digital transmission, using his profit from laying cables for telegraph transmissions. Now the university is going wireless in full throttle.

Let me now talk about the hidden cost of wireless LAN, which makes my research challenging and exciting. Fortunately for us, the government set aside an unlicensed frequency band, the ISM band. You can transmit radio signals within the ISM band if your device talks softly. But the ISM band is a jungle, like the Wild West in the gold rush era. Everyone wants to transmit there: the wireless LAN lives there, so is the Bluetooth---another fascinating 4G technology. Even your microwave oven uses that band. So when you heat up your dinner, someone's email may get micro-waved. Everyone creates and receives interference.

It sounds like a horribly noisy place to live in, and it is. But this is exactly the reason that new techniques will make a big difference. That is why it is exciting.

The Cocktail Party Problem

If I am asked about what research problems I am working on, or if a student who wants to join my group asks for a possible research topic, I would say: let us work on the cocktail party problem.

Say you go to a cocktail party of hundreds of people in Aula[1], this wonderful facility. People are chatting in small groups everywhere, music is playing in the background, and there are a few who seem to get carried away by their drinks, talking annoyingly loud. Some speak in English, others in French, a few in Chinese, most in Dutch. If you think about it, the amount of communications going on simultaneously is enormous. Why can we communicate so well in such an environment that, in many ways, is very similar to the ISM band for wireless LAN? It is not in the drinks, of course, it is in our ability to focus and to ignore, to track and to discard.

How to design communication devices for such an environment is the name of the game.

Let me mention one technique that was attributed to Archimedes. The story said that Archimedes burned the Roman ships that contributed to the siege of Syracuse sometimes around 210 BC. How could he burn a ship far away in the water? Gun powders were believed to be invented in the 8th

[1] Aula is a multifunction facility that includes an the Auditorium of Delft University of Technology where the Cor Wit lecture was delivered.

century. Did the Greeks shoot arrows with fireballs attached? That does not sound like a technique coming out of Archimedes; it got to be more elegant.

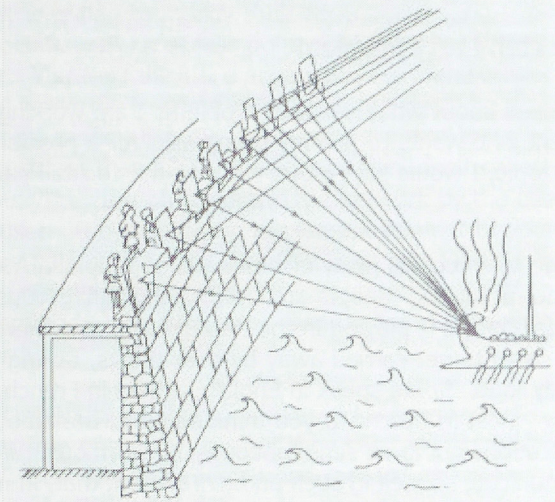


Fig. 7. Artist's impression Archimedes's phase array. [7]

The drawing in Fig. 7 is an artist's impression of what could have happened. An array of mirrors was used to reflect and focus the sunlight on the ship. The rest is obvious. Radio wave behaves just like the sunlight. If you use a bunch of antennas, you could beam your transmission to a particular direction. Fortunately, the radio signal is so weak that the person you talk to will not be fried. You can also use an array of antennas to gather energy emitted from one particular source. This technology is called phased arrays. To appease the ears of investors and the public, "smart antenna" is often used. This is at the core of the BLAST invention at Bell Labs that I mentioned earlier.

Antenna array technology plays several critical roles in wireless. First, it increases the capacity. It can boost the capacity of a 2G channel beyond what is needed for broadcast quality video services. The second function of antenna arrays is their ability of separating simultaneously transmitted signals. It makes you have a tunable ear at a cocktail party, allowing you to listen only to those of interest to you and turning a deaf ear to others. How we human have perfected that art!

How to use antenna arrays efficiently in an interference dominated environment is the focus of my research at Cornell and here at Delft. We develop signal processing algorithms to separate signals from interference, and new network protocols that take advantage the abilities of transmitting and receiving multiple signals at the same time. Here at Delft, with Prof. Alle-Jan van der Veen and Prof. Patrick Dewilde, we consider new techniques that separate colliding packets. All these are part of the exciting research into the next generation wireless, called it 4G, or better yet, call it xG.

The Engineer's Place in Wireless

James Harbord talked about the engineer's place in radio communications in his lecture at Princeton in 1935. Let me comment on the same subject by showing a picture in Fig. 8 appeared in the book, *The Lexus and the Olive Tree,* written by Thomas L. Friedman [8]. It is a scene on December 1998 in Jerusalem. Shimon Biton placed his cellular phone up to the Western Wall so a relative in France could say a prayer at the holy site. The phone seemed to be from 1G, but that is beyond the point. Would a video phone be better in this case? We never know for sure.

Fig. 8. Shimon Biton at the Western Wall in Jerusalem.

The need to hear and to be heard, to see and to be seen is in our genes. While technology does not enhance the content of communication, it makes communications easier, faster, more vivid, longer in distance, wider in space. It expands the horizon limited by our eyes and ears. In spite of the recent plummeting of stock prices and massive layoffs, the match of the telecom industry with the need of our civilization is timeless.

Perhaps engineers should not fall in love with their technology, their Gs, and design things for which ordinary people don't care. Perhaps the wireless market is not the Bluetooth devices emitting advertisements to your Palm Pilot, nor is the smart room which, as you walk in, brews the coffee, turns on the light, and music starts to flow. People can choose for themselves what they like. You don't want smart devices run your life, do you?

For over a hundred years, the telephone companies have served a fundamental need of our society, the need to talk to and hear from someone afar. It is about time they provide visual communications, in real-time, in true color, and in full motion.

It is a wonderful time to study, to teach and to do research in the field of wireless communications. Instead of celebrating this New Year with a few bottles of Heineken, I will get myself a few shares of KPN. It is a bargain.

Dank u wel.

Reference s

[1] The New York Times, December 8, 2000.
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