APPENDIX C. SITE REPORTS—EUROPE

Site: **Alcatel**
54 rue La Boetie
75008 Paris
France

Date Visited: 29 April 1999

WTEC Attendees: R. Pickholtz (report author), M. Iskander, J. Winters, L. Young

Hosts: Vinod Kumar
Alistar Urie
Alain Bravo
Martial Guillaume
Elie Bejjani
Hikmet Sari
Gert Bostelmann

SYNOPSIS

This site is the Corporate Headquarters for Alcatel (Alcatel Telecom plus Business and Corporate). The new organization for Alcatel is a matrix of services and business divisions that operate worldwide. Some highlights of this matrix, as they directly impact or are impacted by wireless technology include:

Services	Networking	Access Systems	Enterprise and Consumer
Network	Radio	- Internet Access	Professional and Consumer
Architecture	Communications	- Transmission Systems	
Division	Division	- Space Products	

Alcatel operates a Corporate Research Center (CRC) with 700-800 people, an IP group of 200 persons, and a Technical Strategy and Standardization program (40 people).

The CRC supports scientific/technical projects for short to medium (2-5 years) terms plus some long-term (8-10 years) projects to prepare for the future. Publication and professional society activity is viewed favorably. CRC is spread over many sites: France (6), Spain, Belgium, Germany, and the United States. Currently there are eight technical departments: software, energy, optical, radio, space, network access, network architecture, and private networks.

M. Guillaume gave a thoughtful and informative talk on both the business prospects of wireless and the emergence/convergence of technologies through 2004. He expects voice traffic to increase by a factor of 2 but non-voice is a major trend that may overtake it. European initiatives to provide Internet services include General Packet Radio Service (GPRS), Wireless Application Protocol (WAP), and the consideration of portable operating systems (OS) such as CE, Palm Pilot, Symbian and Java+. The general feeling is that many companies will contend for dominance of portable digital devices via the operating system, as this will drive applications and services. The OS will also play a large role in the services delivered by wireless.

Alcatel is firmly established in the circuit switched (CS) business but is also moving rapidly to provide packet switched (PS) IP Networks. Alcatel is prepared to offer wireless mobile service via both modes. It was not clear that there would be a strong convergence in the next few years.

Alcatel is also very much involved in satellite communications and has built remarkable technology for radar and signal processing, mostly for military applications. These technologies, however, are quite suitable for commercial adaptation to wireless communications.

In particular, Alcatel developed several working active antenna array systems with beamforming in the K-band, 12.5 – 12.75 MHz only using both amplitude and phase control of 48 subarrays with 3 x 48 control elements.

T/R beam steering antennas with over 6,000 elements have been designed.

H. Sari presented a number of ideas for improving the physical layer performance that are being studied including, but not limited to, turbo codes, multicarrier transmission, improved CDMA plus, informally, a number of theoretical “hot topics” and their likelihood of implementation.

Such emphasis was given to bring the digital processing closer to the antenna by incorporating the low noise amplifiers (LNAs) upconverter and L.O. into a single chip. The bottlenecks for full software radio are high dynamic range, wideband, accurate A/D converter, frequency synthesizers, and good LNAs that are integratable.

Elie Bejjani predicted that wireless might replace the last mile (local loop) even for high speed applications. There was discussion of “mobile dedicated HTML” for encompassing the unique character of mobile links and possible novel applications. Emphasis was placed on PS with IP/ATM or direct ATM Wireless.

Focus topics for research included turbo codes, CDMA optimization, multicarrier improvements (crest factor, synchronization), better, faster power control, study of dynamic effects of power control and optimization, tradeoffs between diversity and array processing gain, and novel techniques for non-coherent modulation/demodulation.

There was considerable discussion about the four-way wireless/wired/CS/PS standards and the ultimate convergence of these parts. Additional discussions included software radio and the European vs. North American approach.

SPECIFIC TOPICS

Alcatel personnel made a series of organized presentations. In addition there were several annual review reports, which convey the sense of direction of work being done at Alcatel in all areas of telecommunications. Wireless communications is one component of this. The distinct impression conveyed was that Alcatel considers wireless to be one component, albeit a very important one, of a vast, emerging global network.

The main thrust of the meeting with Alcatel was systems. The hosts did not address specific hardware devices such as microwave components, physical antennas, or semiconductor technology. However, Alcatel is involved in these areas.

Site: **Centro Studi E Laboratori Telecomunicazioni (CSELT)**
10148 Torino
Via G. Reiss Romoli, 274
Italy

Date Visited: 30 April 1999

WTEC Attendees: N. Moayeri (report author), A. Ephremides, R. Pickholtz, W. Stark, L. Young

Hosts:
Enrico Buracchini, Mobile Services and Radio, Radio Systems, Techniques and Radio Methodologies
Giovanni Colombo, Mobile Services and Radio, Head, Mobile Services
Gaetano Francesco Cazzatello, Mobile Services and Radio, Propagation, Antennas
Claudio Mattiello, Mobile Services and Radio, Propagation, Modeling and Simulations
Agostino Moncalvo, Mobile Services and Radio, Head, Satellites and Microwave Radio Relay Links
Valerio Palestini, Mobile Services and Radio, Head, Radio Systems
Federico Tosco, Head, Mobile Services and Radio

BACKGROUND

CSELT has 1,223 employees, of whom about 826 work in technical areas and have university degrees. The salaries at CSELT are competitive with those offered by the private industry. CSELT is the research arm of Telecom Italia, which provides 75% of CSELT's budget. CSELT's 1997 revenues and investments were $163 million and $28 million, respectively. If Telecom Italy merges with Deutsche Telekom, there will be only one research center. The mobile activities will be at CSELT, and the German side will handle the network aspects. CSELT collaborates closely with CNET in France. There are also collaborations with British Telecom.

Telecom Italia has 126,381 employees and $26.677 billion of revenues. It spends $589 million on research. (The last three numbers are from 1996.)

G.F. Cazzatello gave a presentation on smart antennas. Linear power amplifiers are important for the proper operation of switched beam antennas. Another type of smart antenna is the angle diversity antenna system. In this type of system, the output from several narrow-beam antennas is compared with the output of a wide-angle antenna, and the best signal is selected. That signal is the output of the GSM receiver connected to one of the narrow-beam antennas. The output is the soft decision output of the Viterbi equalizer and before the Viterbi decoding. Ray Pickholtx, a WTEC study team member, commented that one should be able to do better with maximal ratio combining rather than simply selecting one of the signals.

The next type of smart antenna discussed was the adaptive phase array antenna. This antenna tries to reduce interference by adaptively introducing nulls. In the case of adaptive beamformers in the GSM system, there is a 26-bit midamble in each 148-bit frame. This information is used by the adaptation algorithm.

C. Mattiello gave a presentation entitled, "3G Systems Modeling." He emphasized propagation channel modeling in a micro-cellular structure. Typical height of the base station is 3-5 meters. A database of the geographic area is constructed based on aerial photography. This results in a map with a resolution of one meter. The height information for buildings is also incorporated in these maps. The information is then used to create a color-coded map of field strengths in the geographic area. Mattiello showed a profile of delay spreads as a function of spatial position at 1,800 MHz. This was done with a fixed transmitter and a moving receiver in a corridor (perhaps a street). The delay profile in an indoor car-parking garage looked like a mess with many peaks. He went over ray tracing, which is very expensive, and ray launching, which is more tractable but not very accurate. The latter computation was done with 360 rays, one per degree. He showed a comparison between actual signal strength measurements with the ray launching method and with another method taking diffractions into account.

E. Buracchini gave a presentation on software radios. Software radios are not likely to be implemented or used until 2005 - 2010, even if everything goes right. The main obstacles are the need for high resolution ADC/DACs and the complexity of the processing. There was a discussion on how software radios should be introduced. Should there be a common standard, such as Windows CE or Java OS, or should there be proprietary platforms for each provider? What would be best for the manufacturers and users? Most participants felt that a common platform would be superior for all parties involved.

G. Colombo gave a presentation entitled “Network Architecture for 3G Systems.” GPRS should be introduced in the beginning of 2000 for GSM. The problem of macro-diversity in CDMA systems was addressed. In a wideband CDMA system, a mobile might be communicating with a few base stations during soft handover. An important issue is how the higher levels of the network should handle the situation. One possibility is to change the core control point in the network. He talked about the use of ATM Adaption Layers to handle both circuit-switched and IP type of connections on an ATM network.

Site: **Daimler-Chrysler Research Center, Ulm**
Wilhelm-Runge Str. 11
89081 Ulm (Donau)
Germany

Date Visited: 27 April 1999

WTEC Attendees: L. Katehi (report author), T. Itoh, D. Friday, R. Pickholtz

Hosts: Johann-Friederich Luy
Karl-Michael Aldinger
Holger Meinel
Oskar Krumpholz
Karl Strohm

BACKGROUND

The Ulm research facility has a total of 450 researchers and support personnel and is situated 3 km outside Ulm. The whole lab occupies 23,000 sq. ft of clean space including clean facilities from 10,000, to 1, as show in Fig. C.1.

Fig. C.1. Daimler-Chrysler Research Center, Ulm.

The Daimler-Chrysler research labs were reorganized recently. The company follows an R&D 3-vector model in which technological competence, customers, and research programs constitute the three axes of a multi-dimensional research space. The research activities in the Daimler-Chrysler Research Center in Ulm cover five core technology fields:

1. drive systems
2. autonomous systems
3. production and materials
4. mechatronics
5. products and sales

Among the applications that can possibly be covered under these technology areas, emphasis is given to the following:

- communications—to stay in touch while on the move, available at anytime, anywhere
- surveillance—monitoring relevant information to enable adequate actions
- navigation and detection—feel safe and secure about a position, permit personal navigation on a global level

In each of these areas, Daimler-Chrysler and DASA are developing products that address a number of customer needs as shown in Fig. C.2. The wireless communications applications and customer products cover a wide range of high frequencies from 800 MHz to 77 GHz and require high operation speeds from a fraction of a Gbps to tens of Gbps. Research efforts in these application areas include development of software radio, digital receivers, micro-millimeter wave mobile communications and radar systems, contactless sensors, and antenna technology for digital beam-forming for high density TV. In high frequency device development, the company is focusing on the development of III-V based 2.5 GHz and 5 GHz mobile phones. However a serious effort is being undertaken to develop SiGe based devices to accomplish high density and multi-functionality.

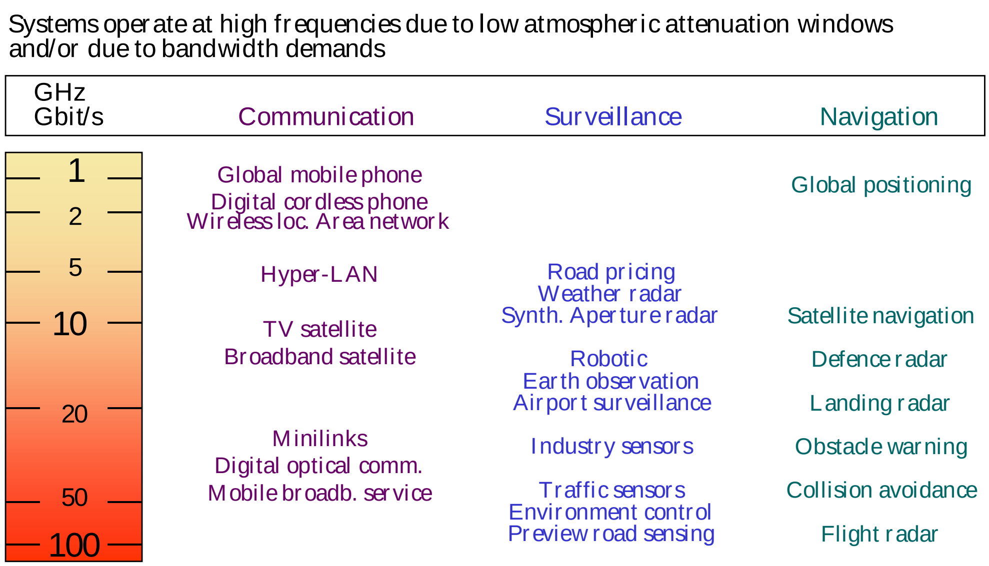


Fig. C.2. Technical trends to meet future society demands.

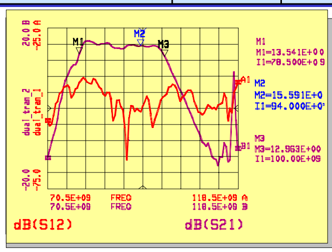
The strength of this center is the development of high-frequency device, circuit and antenna design for the above described communication systems. The research groups have demonstrated world records in InP HEMTS technology (see Fig. C.3).

In addition to InP, Daimler-Chrysler has seriously invested in GaN technology and has demonstrated microwave high power modules with f_{max} above 50 GHz. Effort is presently underway to incorporate this technology into imaging radars operating at millimeter-wave frequencies.

L_G (µm)	0.5$^{\Delta}$	0.25 T	0.20 T
G_m(mS/mm)	600	700	900
I_{Dsmax}(mA/mm)	500	500	600
f_T (GHz)	55	120	130
f_{max}(GHz)	150	250	>300
NF_{min}(dB)/f(GHz)	1.1 / @18	0.6 / @18	2.3 / @60
G_{ass}(dB)/f(GHz)	13 / @18	11 / @18	6/ @60

InP-based HFETs offer performance advantages in:

- **Higher speed** ⇒higher operation frequencies
  ⇒same performance at smaller chip size
  ⇒lower MMIC-costs
- **Lower noise figures**
  ⇒lowest noise figure of any three terminal device
  ⇒ more sensitive receivers, new/cheaper system concepts
- **Lower Bias points**
  ⇒ reduced power consumption
- **Improved power added efficiency at mm-wave frequencies**
  ⇒ reduced power consumption
- **Zero-volt bias mixer diodes possible**
  ⇒reduced LO-power required



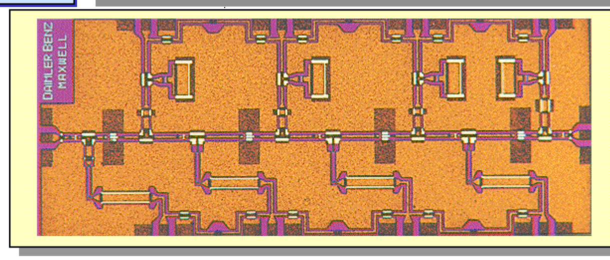


Fig. C.3. Overview of Daimler-Benz InP-based HEMTs.

To achieve high integration and multifunction capability, Daimler-Chrysler is pursuing the development of SiGe-Si microwave and millimeter wave integrated circuits (SiGeSIMMWIC) for range sensors, speed control, etc. In addition to integration and performance, the company expects low cost to be the driver in using this technology in customer products for wireless applications. Such applications include communications and sensing/navigation. Comparisons made between InP-, GaN-, and SiGe-based products show superior cost potential in the SiGe technology (see Fig. 5.11, p. 40) and indicate device superiority due to very low 1/f noise and low phase noise: SiGe transit-time diodes in self-oscillating mixers have demonstrated frequency stability with sub-harmonic locking. Free running has demonstrated about -60 dBc/Hz at 100 kHz from the carrier and with phase locking about –90 dBc/Hz at 100 kHz from the carrier. In this circuit technology, CPW has been chosen as the interconnect medium due to its superiority to thin film microstrip and its associated need of a via hole technology. CPW solves a number of problems but requires an air-bridge technology, which however is easier to make due to its requirements of wafer-surface and not wafer-bulk fabrication.

Daimler-Chrysler is the leader in SiGe technology and has demonstrated performance records in SiGe HBT as shown in Fig. 5.12 (p. 40). A number of SiGe applications include Ka-Band CPW oscillator HBTs, a 77 GHz near-field sensor with SiGe Schottky diodes, and a 77 GHz closing velocity sensor. While SiGe technology is progressing fast, a number of processing issues still need to be resolved. To alleviate some of these issues, passivation of the device by a Si_3N_4 has been adopted. Low temperature, low power cpw-based HBT structures are routinely demonstrated (20 mW at 47 GHz) (6 emitter figure device). At present, research is focused on the development of phase resonant devices with f_{max}=300 GHz achieved by quantum-well injection.

Daimler-Chrysler is inserting this technology into customer products via an extensive product development effort performed in the “Microwave Factory” owned by DASA. This facility called the “M5-Service Center” (Microwave and Millimeter-Wave Module Engineering and Manufacturing Services) enables the development of products based on the research of the various D-C research centers. This center has 84 staff members, occupies 10,000 sq. ft. of dedicated space, and has a DM 17 million measurement facility in addition to the fabrication facilities. Sensors such as SatCom, MobilCom, Cruise control at 77 GHz, and LMDS at 28 GHz, as well as a 24 GHz radar designed to measure material properties for application in steel production, have been produced. Other products include a 58 GHz point-to-point link in hybrid formulation with GaAs MMICs using bonding wires for connection to MMIC chips. This facility has been sole supplier to many communications companies (including Nokia) and focuses on defense/space products for guidance and communications, with 60-70% in defense and 30-40% in commercial communications. The antenna group of DASA does all antenna measurements.

In communications technology, Daimler-Chrysler is investing in telematics, advanced media and services, information technology, and software technology. Efforts are focused on application specific solutions for a variety of services including vehicle IT systems, personalized security systems, vehicle integration antennas, vehicle networks, multi-agent systems, and object oriented techniques. Other applications include the following:

- Internet to the car by using flat panel displays
- Motiv: telemetric project to develop a traffic routing system using GSM (0.9-2.5 GHz)/DAB (1.8)
- Game: Global Automotive Mobile Entertainment
- error recording via Radio LAN
- digital radio via a short wave communication system (2-9.6 kB/s)
- mobile broadband communication systems (complementary of UMTS)
- 150 Mbps up to 5 km range wireless and mobile based on ATM
- ATM mobile (see above)
- fast train communications (38 GHz), among others

In addition to the above, Daimler-Chrysler is developing optical back planes for board-to-board interconnection. The back planes interconnect high-performance signal processors for modular avionics that require 1-8 Gbps and require serial buses instead of parallel busses. The backplanes are designed in ring or star configurations. Back planes offer advantages over space transmission since they provide a vibration-free solution. Free-space transmission and optical guidance through a polymer wave-guide give a 3 dB loss with an axial tolerance > 2mm and lateral tolerance better than +-500 micros. Power budgets are very critical, and wave guide attenuation better than a few dB/m is required to make designs successful. Polymer optical wave-guides with 1-3 dB/m attenuation in the short wave are used and are coupled through mirrors for good efficiency and low spillover. This technology has been demonstrated in a 1 Gb application. The length of the back plane was 26 cm and exhibited 3.5 dB loss. Demonstrated system margin was approximately 10 dB. Planar optical wave-guide crossing loss =0.7 dB, and line loss can be improved by anti-reflection coating. Total loss can be as low as 2.5 dB. An issue that needs to be addressed is the collection of particles on the transitions of the optical wave-guide or on the lenses. Vibration tests have shown excellent potential and aging tests of the low-loss wave-guide (200 hours) have indicated no increase in losses. Possible applications may provide 2.5 Gbps, while interconnection lengths up to 19 inches have been achieved.

Site: **Ericsson Radio Systems AB**
Torshamnsgatan 21-23
164 80 Stockholm
Sweden

Date Visited: 26 April 1999

WTEC Attendees: N. Moayeri (report author), A. Ephremides, M. Iskander, R. Rao, W. Stark, J. Winters, L. Young

Hosts: Soren Anderson, Manager, Antenna Systems and Propagation Research, Ericsson Research, Corporate Unit
Hakan Eriksson, Vice President and Gen. Manager, Ericsson Research, Corporate Unit
Hakan Eriksson, Manager, Radio Access Research, Terminals
Ulf Forssen, Director, System and Technology, Business & Product Line Management TDMA Systems
Bjorn Gudmundson, Research Director, Radio Systems
Bo Hedberg, Senior Expert, Radio Technology Research
Johan Skold, Expert, Digital Radio Access in Cellular Systems, Radio Access and Antenna Systems Research
Anders Khullar, Ericsson, Lund

BACKGROUND

The panel visited the Radio Systems division of Ericsson, where most of the R&D work related to wireless communications is carried out. Ericsson, however, is much more than this and is active in many other areas of electrical engineering and information technology. The most important and active area of wireless communications from a commercial point of view, as the 21st century approaches, is the development of 3G wireless communication systems. The International Telecommunication Union (ITU) is vigorously pursuing the development of the International Mobile Telecommunication 2000 (IMT-2000) standard for 3G wireless systems, which it intended to complete by the end of 1999.

Ericsson is a powerful voice and a major player within the European Telecommunication Standards Institute (ETSI), which is the sponsor of the W-CDMA proposal for the IMT-2000 standard. Ericsson has had the largest share and contribution in the development of Bluetooth, which is a short radio for wireless LAN type applications in the 2.4 GHz ISM band. To be more precise, Bluetooth is a cable replacement device that connects all personal computing and communications devices to each other in a wireless fashion. In fact, it is to be used even in future home appliances if all goes well with its development by Ericsson, IBM, Intel, Nokia, and Toshiba.

The first presentation was given by Hakan Eriksson, Vice President and General Manager of Ericsson Research, about the areas Ericsson is involved with and some facts about research in areas of high technology in Sweden. He said that universities are now more involved in industrial research in Sweden. They work closely with Ericsson. He then talked about the distinctions between 3G and 4G wireless systems. In case of 3G wireless, the spectrum had been clearly specified from the outset. It is much harder to define 4G wireless, because the spectrum has not been defined. He showed a slide of different wireless systems on a bit rate vs. mobility (fixed, local area, wide area) plane. He talked about three scenarios for voice-over IP.

The first scenario is what we have today. He also compared several scenarios (cases of sending various types of data) in traditional ways and over a wireless network. He showed that wireless made more sense than the traditional ways in a number of cases, i.e., it was cheaper, at least with the present pricing structure we have today. He also showed that for email, wireless is a lot better, but for images and video, traditional ways are still better. He stated that it would be very unlikely that people would watch video on a small pocket-sized terminal. However, such terminals would be good for voice, email, postcards, and music.

Bjorn Gudmundson explained that research at Ericsson has a shorter horizon than the 10 years that WTEC study team member Tony Ephremides mentioned in his talk. Gudmundson added that the Ericsson staff present at the meeting all worked on radio aspects, and that they would not be the best people to answer network-related questions such as whether ATM or IP was the best alternative for sending voice and some other types of data over the network. There are some experts in those areas at Ericsson, but they were not present at the meeting. Regarding ACTS, FRAMES, and other such programs administered by the EC, Gudmundson said that he believed that those programs were not very efficient, as there is a lot of paperwork and overhead. On the positive side, these programs represent a framework for industry to work closer with universities all over Europe. But then Ericsson has had good informal relationships with the universities for many years.

Bo Hedberg gave a talk on multi-standard, multi-carrier, wideband radios. Multi-carrier radios have to handle much larger dynamic ranges. That means stricter requirements on the A/D, D/A, and the multi-carrier power amplifier (MCPA). Some part of their architecture can be controlled digitally and through software. The RF front-end generally is not controllable. He said that power efficiency was important not just at the mobiles but also at the base stations. Otherwise, they would have to use large fans to keep the MCPAs cool, and that would increase the price quite a bit. The dynamic range in multi-standard, multi-carrier, wideband radios would increase by about 20 dB over present systems (GSM). Half the cost of future base stations will be in the MCPA. The present price for this component is about $100 per watt of average RF output power.

Hedberg felt that a lot of research was needed during the next several years to improve the MCPAs. He concentrated on the base station, because he thought the problem was harder for the terminal stations. He felt that the software radio solution was very costly for terminals. The technology needs to mature before it can be used at terminals. Note that the multi-carrier requirements at the terminals are much looser than in the base stations. The 1 microsecond frequency-hopping rate discussed refers to the radio at the base station. It is not possible to have such a high rate at the terminals. The present rate used at base stations, based on analog synthesizer techniques, is one frequency hop per millisecond.

Soren Anderson gave a talk entitled, "Adaptive Antennas in Wireless Systems." He outlined possible alternatives for smart antennas and space-time processing. He presented a general radio architecture for taking advantage of these concepts. As always, the interesting question is how much benefit would one get for the cost? In cellular systems, the downlink is usually the bottleneck due to interference. So, when it comes to smart antennas and space-time processing, it is best to concentrate on the downlink. In an FDD system, for example, one knows a lot more about the characteristics of fading in the uplink direction than in the downlink direction. In a TDD system, one has a different situation.

Anderson then talked about the potential benefits of smart antennas in GSM downlink transmission. He showed a 5-6 dB improvement at the mobiles. Yet another example shows that with sector antennas the quality drops very quickly in comparison with smart antennas. The measure of quality was probability of frame error rate being less than 2%. Note that power control is independent of what was discussed here. PC has its own gains. Also note that to get the maximum benefit of smart antennas in a heterogeneous network, one needs to have good estimates of the traffic distribution in the cell.

Bjorn Gudmundson talked about radio access technologies. He said that mobile Internet access will be the main driver for wireless systems in the future. As far as fourth generation (4G) wireless is concerned, it is not clear whether it should provide much better coverage-bitrate performance or somehow combine in an architecturally sound fashion a variety of systems such as LMDS, Bluetooth, WLAN, IMT-2000, mobile satellite systems, etc. He then concentrated on the evolution of cellular systems by showing 2G, 2.5G, and 3G systems. He put the EDGE system in the 3G category. He talked about the structure of dedicated physical channels in W-CDMA. He said that it was harder to use smart antennas in IS-95, because it handled the pilot bits differently than in W-CDMA. He then compared GSM and EDGE. In GSM the modulation is GMSK, which transmits one bit per symbol. EDGE uses 8 PSK. The concept of adaptive coding and modulation helps EDGE adapt itself to the link quality. He went over major differences between W-CDMA and CDMA2000. He then talked about certain indoor systems (WLAN, Hiperlan-II, and Bluetooth). The distinction between Bluetooth and HomeRF was questioned. Gudmundson did not have any comments about HomeRF.

Ulf Forssen talked about EDGE and how it related to GSM and W-CDMA. It is, of course, an extension of GSM. He discussed the relationships between EDGE, GSM, and TDMA/IS-136, as well as the tradeoff between spectrum efficiency and average throughputs. In summary, EDGE offers a way to harmonize GSM and IS-136. It has been approved by ETSI and UWCC and has been submitted to ITU. It will provide global roaming for a very large user base.

Johan Skold talked about W-CDMA. He went over a number of features of the UTRA system.

Hakan Eriksson, Manager of Radio Access Research, gave a presentation on mobile terminals. He talked about their present terminals and future directions. He also talked about some possible applications. In addition, he talked about Bluetooth and the Wireless Application Platform (WAP) Forum. Symbian (Ericsson, Nokia, Motorola, and Psion), which is an open architecture, allowing different software developers to develop new applications for these terminals, was also discussed.

Anders Khullar's talk was titled "GSM Terminal Evolution." He discussed positioning systems and their impact on mobile price. He covered TOA, OTD, and GPS. He is with Ericsson, Lund.

Site: **Filtronic PLC**
The Waterfront
Salts Mill Road
Saltaire, Shipley
West Yorkshire BD18 3TT
United Kingdom

Date Visited: Friday, April 30, 1999

WTEC Attendees: D. Friday (report author), M. Iskander, T. Itoh, R. Rao, J. Winters

Hosts: Professor J. David Rhodes, Chairman, Filtronic plc
Professor Christopher M. Snowden, Director of Technology, Filtronic plc
Professor Peter Clarricoats, Chairman Technology Advisory Board, Filtronic plc and, Chairman, Defense Scientific Advisory Council, Ministry of Defense, UK
Eric G. Hawthorn, Engineering Director, Filtronic Comtek
Dr. Richard G. Ranson, Director, Subsystems Engineering, Filtronic Comtek
Alan Needle, Managing Director, Filtronic Comtek

Additional unidentified participants came and went throughout the day

FILTRONIC PLC, THE COMPANY

Filtronic was founded in 1977 and is a public limited company (plc) incorporated in England and Wales. Professor Rhodes has been Executive Chairman and Chief Executive Officer since its founding. The company is multinational, with several subsidiaries in Europe, Australia, and North America, and it is a world leader in the design and manufacture of a broad range of products for communication across the radio-frequency (RF) spectrum. These products include microwave and millimeter-wave devices, components and subsystems for wireless communications, cellular handsets, components for hardwired networks such as cable TV and high-speed Internet access, and electronic warfare systems. The company claims to be able to supply products at any frequency, for every transmission standard and every modulation system in the world. Its products primarily receive, transmit, filter, and amplify RF signals. Markets are categorized in four broad areas. These markets, and the percentages of Filtronic's business in each of these areas in 1998, are as follows: Wireless Infrastructure (55.8%), Cellular Handset (26.4%), Electronic Warfare (17.1%), and Cable (0.7%). In 1998, the company had sales of £181.1 million ($295.3 million), almost all its wireless business being mobile cellular. The focus in this report will be on the commercial wireless communications aspects of the business, the first two categories and 82.2% of Filtronic's business.

In 1989, Filtronic bought Philcom Microwave, the first of its U.S. interests. This gave Filtronic a technological edge with which to move, more rapidly, into the base station and mobile communications market. In 1994, the company went public on the London stock exchange. The commercial communications market is Filtronic's primary customer base, and national-defense agencies form a second customer base. Filtronic supplies the latter with electronic warfare equipment and systems. The electronic warfare (EW) part of the business remains privately owned and provides access to the U.S. defense market. The advanced defense technology, especially in communications, also provides Filtronic with a critical edge for commercial applications. In the United Kingdom, Filtronic has facilities in Shipley (the Corporate Headquarters and WTEC visit site), Stewarton, East Kilbride, Wolverhampton, and Milton Keynes. The U.K. activities include the design and manufacture of wireless and cable products, EW products, and ceramic and ferrite wireless components. Filtronic has facilities (LK Products) in Kempele and Oulu, Finland, for the design and manufacture of access and subscriber products. In its Brisbane, Australia, facilities Filtronic designs and manufactures wireless and EW products. In the United States, the company has facilities in

Salisbury Md., Merrimack, N.H., Santa Clara, Calif., and Natick, Mass. The more recent of these U.S. acquisitions include Litton Solid State, Sage Laboratories, and subsidiaries.

Primary commercial customers are the leading international original equipment manufacturers (OEMs). Filtronic plc employs approximately 3000 employees worldwide, including 250 engineers, of whom 10 % have Ph.D.s. Filtronic refers to its worldwide holdings and resources as the "Filtronic Group." The Filtronic strategic goal is to become the pre-eminent supplier of RF, microwave, and millimetric products.

FILTRONIC PLC, THE TECHNICAL PROGRAMS

Materials

Filtronic management, early on, saw materials as critical to competitiveness in wireless technology and acquired a U.K. ceramic and ferrite manufacturing company. The main materials-technology roadmap is focused on requirements for ceramic resonators. The fundamental challenge is price vs. performance for the components produced with these materials. Good performance means lower-losses (higher Q), higher dielectric constants (size reduction), and invariance of the material properties under changes in temperature. Present low-cost ceramic resonators have Q-values ranging from 15,000 to 20,000, and are based on ceramics with dielectric constants ranging from 35 to 45. Current, high-end ceramics have dielectric constants from 45 to 55 and achieve Q-values of 30,000. Filtronic representatives stated that one of the targets was a resonator, at 1.96 GHz, with a loaded Q of 50,000. Their roadmap predicted high-Q resonators with dielectric constants ranging from 70 to 200 in 5 years.

Base Stations, Amplifiers, and Filters

Base station technology is another key element in Filtronic's corporate planning and roadmapping efforts, with amplifier and filter performance the key issues. Dual-mode conductor loaded ceramic and high-Q combline filters are mid-priced and also mid performance (unloaded Qs of 5,000 to 8,000). TE (0,1,d) and dual-mode TE (0,1,d) filters achieve unloaded Qs of 50,000 but at twice the price. There is a need to drop the price of these components. Filtronic is leveraging the Sage acquisition for base station coupler technology. The wireline technology is low cost and yields high performance among competing technologies. Ferrite components and their manufacturing processes for planar circulators is another base station technology the company is roadmapping.

Filtronic sees three viable options for base station filter technology for 3G: GPRS, EDGE, and W-CDMA. One option is modular systems including integrated systems, micro-controllers, and highly linear power amplifiers. The second option is TE (0,1,d) ceramics technology including multimode, helical, and other designs. The third option comprises improved versions of more traditional machined combline filters. Filtronic's dual-mode conductor-loaded ceramic technology has enabled a one-half size reduction. The insertion loss is 0.5 to 1 dB for a typical base station. These devices have a very good Q (not given) and are the result of an 18-month development period combining both ceramics technology and metalization technology.

Filtronic does not have any projects for using high temperature superconductors (HTS) for base station filters. They cited the nonlinearities and reliability as factors that make HTS technology less attractive as a product line. Filtronic also believes that advances in conventional technology have marginalized the performance gains of HTS hardware.

3G hardware will require improved linear amplifier technology and better efficiency, particularly for wideband CDMA. Software radio is doable—there should be no problems at the lower frequencies. Transceivers need to be cost effective. There is a need for distributed switching systems in base stations. One objective is to make a significant advancement (details unavailable) in Class A amplifier performance by September 2000. Filtronic is taking an integrated approach, without close project management, and researchers believe they have a key advantage—special expertise and proprietary software for integration of complex filters.

Base Station Antennas

Prof. Rhodes discussed the issue of the higher power (approximately 20 dB) needed for base stations to have the same coverage for high data rate systems (such as EDGE) as for current mobile radio systems. He discussed the use of adaptive antennas, in particular, pencil beam phased arrays on the uplink and downlink at base stations to provide a higher gain. Key research issues were seen to be multiband phased array antennas for base stations, along with filters and efficient and linear power amplifiers. Tower top electronics were also seen as an issue. The use of terminal adaptive arrays was not felt to be practical (because of the expense), as was the use of higher frequencies (because of diversity issues with point-to-point links). DSP power was not felt to be a concern. Other Filtronic comments regarding base-station antennas were "we can't get away from pencil beams from the base stations," and "multibeam RF is absolutely necessary and difficult."

Fixed Broadband Wireless

Comments concerning LMDS implied Filtronic does not see a wide market for this. Researchers said that LMDS in the United Kingdom was licensed in the frequency band 40.5 to 43.5 GHz. Experiments performed led them to the conclusion that propagation reliability will be poor with the moist and rainy weather typical of the United Kingdom. They said that point-to-multipoint architectures were not likely to succeed and that perhaps multipoint to multipoint would be a better architecture — a dynamic network in which every user would be a possible relay-node. They didn't see such an architecture being acceptable in the more privacy and security conscious United States. They also feel that most demands can be met with existing bands, and envision 1% of the market for LMDS, mostly wireless local loops. They also said one of their subsidiaries (Radiant Networks plc) had a 25 Mbps wireless technology and that LMDS is not right from either standpoint.

Wireless Handsets

The purchase of LK Products has extended Filtronic's expertise and its market to include handsets. Customers now include Nokia, Ericsson, Siemens, Bosch, AT&T, Hyundai, etc. Clearly, the only directions here are to make the handsets smaller, less costly, and more multifunctional and to improve their performance. Since handsets are simply housings for the real technology, the only solutions are in advances in the components discussed elsewhere. Filters are a key component and in addition to the ceramic technology discussed under "Materials," surface acoustic wave (SAW) filters are showing promise. Helical filters, traditionally used in handsets, will likely drop out of use as ceramics and SAW improve. The one exception is the handset antenna and integration of the antenna with its housing as well as the RF front end. Improved integration was seen as a key issue here. The cellular air interface also needs attention, particularly the antenna technology, the effects of hand placement, and the user-body effects on antenna performance. Additional comments were "3G specifications, such as 2 Mbps are political issues," "GSM will be driven by power requirements," and "multi-antenna handsets will be essential."

Semiconductors

Filtronic does not use HEMTs but developed a capability (by acquisition) for fabricating pHEMTs. Their pHEMTs have very high linearity, TOI up to 20 dB above P-sub-I. Researchers developed the capability for producing MMICs up through mm-waves. Filtronic now has MBE and E-Beam capability, several class 1000 and Class 100 Clean Rooms, and GaAs, InP, and YIG fabrication technology. Filtronic sees semiconductors as one of the most critical technologies, where it needs to maintain cutting-edge capabilities in design and manufacture, in order to remain competitive. The hosts had an interesting observation on competing semiconductor technologies particularly SiGe: They see the frequencies for Si technology being pushed much higher and the costs for GaAs being pushed down. The end result is that SiGe technology will lose its perceived advantage and drop out as an alternative for wireless. The company has no SiGe fabrication capabilities.

General Comments on Wireless Bands: Low Frequencies

Everyone will go to the limits to use these frequencies as much as possible. Some applications assumed to be the domain of higher frequencies will be done in the future at lower frequencies, and industry will develop much more competence at exploiting these frequencies.

High Frequencies

Receiving much attention at present, but the ultimate applications and implementations will have to sort themselves out. Many technical (hardware) challenges remain before this technology is competitive. Most demands can be met in the existing band.

SUMMARY/CONCLUSIONS

Filtronic Wireless Vision, Research Recommendations

Chairman Rhodes stated in his overview that the company's technological niche requires that it operate in one of the world's most highly competitive markets. Very rapid advances in technology characterize this market and its industries. Filtronic, he said, competes on the basis of cost, quality, performance, and manufacturing and delivery deadlines. All R&D and corporate acquisitions are directed toward advancing the technology, the expertise, and the production capability necessary to stay even with or ahead of the competition for the next major procurement contracts. If Filtronic falls behind, it will be adversely affected, and even its OEM customers may become competitors if they can manufacture equivalent products at less cost. Filtronic has a long-term planning process and showed us for perusal (but did not provide) a proprietary copy of their strategic plans, the Filtronic corporate roadmap. Our perspective however, was that the technology requirements forecasting process was critically driven by the need to make the next logical improvement in existing devices, components, and subsystems. The rationale was clear. If the company's product is not competitive in the next few rounds of procurement competition, the long-term future will be irrelevant. Although this essential aspect of the planning process was in the forefront, it was balanced by a longer term vision that encompassed new technologies, experimentation, and prediction of customers' needs through the year 2005. Director of Technology Snowden stated that the horizon was only 5 years out, due to the rapid evolution of markets and technology. William Smith, who spoke regarding the manufacturing operations, said the basic mode of operation is "get the call today, deliver the product tomorrow." A typical product may go from specifications to a volume-manufactured product in less than eight weeks. This is clearly a very difficult environment in which to do long-term technology forecasting. However, Filtronic did develop and provide insights into the next steps in wireless hardware improvements.

The Filtronic management left the WTEC study team with its vision of the five key research topics that, over the next five years, will have an important impact on future wireless communications technology products. The key topics are the following:

- systems perspective: systems architecture, hardware/software-integration/optimization
- smart antenna systems
- power amplifiers for both handsets and base stations
- filters (including materials)
- digital signal processing to enable more efficient use of hardware

Filtronic hosts stated that performance is the bottom line and given the success and rapid growth of Filtronic plc since its inception, this vision may not be too far off.

Site: **GMD FOKUS**
German National Research Center for Information Technology,
Research Institute for Open Communication Systems
Kaiserin-Augusta-Allee 31
D-10589 Berlin
Germany
http://saturn.fokus.gmd.de/fokus/

Date Visited: 29 April 1999

WTEC Attendees: R. Rao (report author), A. Ephremides, N. Moayeri

Hosts: Eckhard Moeller, Head of Competence Center PLATIN
Mihai Mateescu, Head of MOBRA
Christian Schuler, member of MOBRA

SUMMARY

Forschungsinstitut für Offene Kommunikationssysteme (FOKUS) or the Research Institute for Open Communication Systems was formally established in 1988, but its roots can be traced to the much older Hahn-Meitner-Institut in Berlin. It had then and continues to have an institutional focus on providing "information at any time, at any place, in any form, and according to personal preferences." GMD FOKUS undertakes research and pre-product development work on a variety of communications and computing initiatives.

FOKUS draws 30% of its support from the German government. The remaining 70% comes from companies like Deutsche Telekom and Textronix in Germany, Hitachi and NEC in Japan, the Racal Data Group in the United States, from E.U. programs like ACTS and ESPRIT, and from national R&D programs such as the German Research Network (DFN).

FOKUS takes part in a number of technological developments through R&D projects, management and development of international test beds, software and hardware prototypes, and product development. FOKUS is an active contributor to main standardization bodies such as OMG, EURESCOM, TINA-C, ATM Forum, TMF, IETF, ETSI, ISO, and ITU-T, and is active, as well, in education at universities (in particular the Technical University of Berlin) and other organizations. FOKUS has experience in developing working demos, and an essential part of its success in this regard comes from extensive industry involvement not only in donating equipment but also in setup and testing.

The organizational structure at GMD FOKUS and the funding mechanisms pursued exposes researchers to market forces. Although this exacts a price in the management of projects and recruitment and retention, research personnel seem to be engaged in relevant work.

About 20% of its 185 employees are permanent and the rest are hired for terms not exceeding five years. The permanent staff provides leadership and continuity. The temporary staff is hired for specific projects and the duration of their appointments are directly tied to the duration of the projects. This is viewed as a source of some difficulty in hiring and retention.

Discussions with key senior personnel spanned issues pertaining to network centric and user centric support for mobility, hybrid fiber radios, scheduling for the wireless channel, error control, fourth generation systems, cellular IP, and software radios.

Drs. Mateescu and Moeller, the WTEC panel's gracious hosts at GMD FOKUS, believe that competition is key to driving down the costs of access as well as the provision of proxy services to untethered mobile users.

As far as mobility support was concerned, they saw particular merit in two architectures/technologies: architectures involving smart network resident agents that shadow mobile users and serve up appropriately reformatted information to low cost terminals and architectures where the mobile exercised more control and relied on network infrastructure primarily as a low cost transport medium.

Dr. Mateescu believes that communication is about information exchange. Large databases will be used to store this information, and therefore he sees high bandwidth optical networks as a key element of the overall communication infrastructure. In this context, an ongoing project on Hybrid Fibre Radio at GMD FOKUS was described to the panelists. The system incorporates passive devices that convert optical signals to RF and vice versa. The architecture allows for the deployment of many low cost antenna/converter subsystems that are linked to a more central base station. EURESCOM (www.eurescom.de), a pan-European institute for strategic studies in telecommunications, has an interest in understanding how this and other such technologies would affect the business of European telephone service providers.

Although research driven by market forces has its appeal, Dr. Mateescu indicated that a new hurdle in securing commitment of market actors for long-term projects was not the fear of failure but the fear that the work might become irrelevant in today's rapidly changing environment. Senior leaders remain confident that through nimble management, the quality of the research at GMD FOKUS will remain high but some concern was expressed about the quality of life of the researchers. An example of a long-term research project at GMD FOKUS within the confines of a standard was the development of packet "scheduling algorithms over the RF channel." This was viewed as a key point of differentiation between competing UMTS compliant data service providers.

GMD FOKUS was starting to explore "Fourth Generation" concepts in collaboration with major equipment manufacturers. At the current time, this new generation was viewed as extending the range and mobility support for broadband wireless access. Investigations were also underway on the concept of "Secure Cellular IP Networks." Long-term research plans at GMD FOKUS include MAC, FEC/ARQ, software radio, HFR, radio independent access, and mobility routing. Applied research is focused on hardware/software prototype development, and GMD FOKUS does get involved in pre-product development through the creation of networking software and software tools.

FOKUS ORGANIZATIONAL STRUCTURE

FOKUS was recently structured around nine centers of competence:

1. CATS, the Competence Center for Advanced Network Technologies and Systems, is focused on the development and implementation of new communication protocols, systems and services.
2. GLONE, the Competence Center for Global Networking, is focused on Internetworking services over various underlying technologies, enabling global communication, services procurement, and service quality guarantees.
3. MAGIC, the Competence Center for Multimedia Applications for a Globally Interacting Community, is focused on various aspects of interworking communication systems including issues of convergence.
4. PLATIN, the Competence Center for Distributed Object Technology, Platforms, and Services, aims to support new business opportunities that emerge from value-added, customized service provisions.
5. ECCO, the Electronic Commerce Competence Center, offers products, services, and consultation on the design, specification, and development of electronic commerce platforms and applications based on state-of-the-art technology.
6. IMA, the Intelligent Mobile Agents Competence Center, offers services and consulting on the definition, specification, and development of agent platforms and applications based on state-of-the-art Intelligent Mobile Agent technology.

7. MOBRA, The Competence Center for Mobile and Broadband Wireless Communications, pursues advanced R&D for protocols, interfaces, and applications of mobility in wideband/broadband multimedia networks.

8. TIP, the Competence Center for Testing, Interoperability and Performance, offers services and consulting on analyzing, testing, measuring, and monitoring LAN and WAN components and applications.

9. OKS, the Competence Center for Open Communication Systems, investigates technologies, platforms, and services to provide universal service access.

Site: **German National Research Center for Information Technologies (GMD)**
IPSI—Institute for Integrated Publication and Information Systems
Dolivostrasse 15
D-64293 Darmstadt
Germany

Date Visited: 28 April 1999

WTEC Attendees: A. Ephremides (report author), R. Pickholtz, L. Katehi, T. Itoh, D. Friday

Hosts: Professor Dr. Wolfgang Schoenfeld
Mr. Matthias Hollick, GMD-IPSI
Ms. Nicole Berier, GMD-IPSI
Professor Dr. Ralf Steinmetz, Professor, GMD-IPSI and Technical University of Darmstadt
Dr. Lars Wolf, Technical University of Darmstadt
Ms. Ana Pajares, Technical University of Darmstadt

BACKGROUND

GMD is the principal research organization of Germany that is primarily publicly funded and that focuses on information technology. Although detailed budget figures were not presented, a broad picture of GMD's activities emerged from the discussion. The organization is composed of eight institutes each of which focuses on separate (although interrelated) sectors of research activity. Four of these institutes are located in the Bonn area (along with GMD's headquarters); two are located in Berlin; and two in Darmstadt. IPSI focuses on information distribution. As such it encompasses activities in the following:

- information management
- digital libraries
- information "publication" (in the broad sense of the term)
- future working environments
- mobile interactive media
- cooperative environments

The main activity of the institute that formed the basis of the discussion for the purposes of this study was that of mobile interactive media. As it emerged from the discussion, the main thrust of IPSI's efforts in this area are focused on the upper networking layers (i.e., on the effects of mobility and of dynamic environments on network protocols) and not on the wireless medium per se.

There is close interaction between personnel at IPSI and the research staff (faculty and students) of the Technical University of Darmstadt. In fact, at the WTEC meeting, representatives of both organizations participated.

DISCUSSION

After the WTEC panel made a brief introduction and described the objectives of the study, Professor Dr. Schoenfeld proceeded with an extensive review of IPSI's programs on mobility issues. Later Professor Dr. Steinmetz joined the meeting and complemented, with a brief commentary, the presentation of Dr. Schoenfeld. After lunch, Dr. Wolf described some additional projects that are jointly pursued by IPSI and the Technical University of Darmstadt. The meeting concluded with a broad discussion among all the participants.

The main focus of IPSI's programs in mobility studies is on seamless roaming for interactive multimedia in dynamic environments in which the logical connectivity among the hosts and the routers is changing. As such, it concentrates on the higher layers of the communication process.

As described by Dr. Schoenfeld, the objective of mobility tracking is to maintain consistent information about every node's connectivity throughout the network. The networks of interest include WLANs, cellular networks, fixed wireless systems, and even systems with satellite links. When an end-node in a routing tree changes position, well-developed and well-understood methods of registration and reporting (from cellular networks) can be used. However, when intermediate nodes change position and connectivity, then the method of "tunneling" can be used. This method has formed the basis of mobile IP and represents a short-term solution since the resulting new route is in general non-optimal. The long-term solution would have to be based on rerouting. This is not easily accomplished in IP networks. Ongoing and future research on this issue is addressing this problem.

In a sense, the search for improved solutions in this context suggests that routing in ad-hoc networks is an important area that may have useful fallout in mobile computing. In fact, the DFN-Verein, which operates the network that interconnects universities and research institutes in Germany, maintains an interest in mobile computing and, through a new program, called MIRIAM, will permit IPSI to test the use or the modification of mobile IP as part of the research in adaptive routing.

A related problem that IPSI is investigating involves the continuous registration of a mobile host at a (possibly remote) home agent. The research concentrates on the theoretical modeling of this issue and on the resource management problem that arises when links that support different quality of service must be chosen. An E.U. project called COSMOS, in which IPSI is participating, addresses this issue. The role of IPSI in this project, which assumes the use of satellite links as well, centers on middle-ware development.

Although IPSI recognizes the importance of the effects of the wireless link on the higher-layers (e.g., QoS vis-a-vis mobility), its primary concern is the development of upper-layer protocols that are compatible with, or are optimized for, dynamic topologies. By the same token, these upper-layer issues are crucially important and, yet, are usually ignored by the physical-layer community.

To handle environment changes, a service location protocol is needed and a classification of services is necessary in order to determine which services should be provided at which location. In this regard, it was clarified that location refers to the notion of topological connectivity and not of actual position coordinates (which is an objective of E-911 in the United States for future wireless services).

To assist in these projects, a Mobile Network Emulator is being developed that will actually include a link propagation model.

In response to a question from the panel, it was clarified that multicasting applications are not currently part of the focus in the IPSI projects.

The meeting, as mentioned earlier, included a description by Dr. Wolf, of the projects that are jointly studied by the Technical University of Darmstadt and IPSI. These include a variety of topics that revolve around multimedia networking from the point of view of content and information distribution. Some of these topics are quality of service, heterogeneity, Internet telephony, security, gateways and protocols, content processing, distance education, middle-ware, video servers, and content distribution. As the nature of these topics makes it clear that the emphasis is on general networking and not on wireless networking. Nonetheless, the relation to mobility (from the point of view of long-term mobility, i.e., the prediction of needs at different locations) renders this research relevant to wireless networking. Also, the issue of pricing of services, which in its own right has long-term implications for Internet networking as well as for wireless communication, is on the research agenda of IPSI and the Technical University of Darmstadt.

In the ensuing broadened discussion, in which the panel's hosts were explicitly asked to address the long-term research issues and bottlenecks in wireless and mobile networking, it was mentioned that there is a 2005 Master Plan for IPSI. This Master Plan encompasses the areas of media streams (including entertainment services), ubiquitous computing, education, applications (such as telemedicine), and technology (e.g., security). Furthermore, it was pointed out that the ultimate bottleneck in network communications would be the "usability" of the products and services, i.e., the needs and capabilities of the consumer and user.

SUMMARY

The visit at IPSI highlighted issues in wireless networking that are often ignored by the wireless community, namely the need to address the design of upper-layer protocols and their effects on link operation. However, the WTEC panel visit verified that an integrated approach to networking that bridges gaps among layers is needed but not yet in place.

Site: **IBM Zurich Laboratory**
Communication Systems Department
Soodmattenstrasse 8
H-8134 Adliswil
Switzerland

Date Visited: 29 April 1999

WTEC Attendees: T. Itoh (report author), D. Friday, L. Katehi, W. Stark

Hosts: Dr. Pierre R. Chevillat, Mgr. Wireless Communication System
Mr. Martin Hug

BACKGROUND

The panel visited IBM's Zurich Research Laboratory in Switzerland and, more specifically, its Communication Systems Department, located in Adliswil in a suburb of Zurich. This building is several kilometers from the main laboratory. It is planned for this building to be vacated shortly, as this department will be relocated to the main site. This is one of eight research laboratories of IBM. The others are the T. J. Watson Research Center (headquarters), the Almaden Research Center, and the Austin Research Laboratory in the United States. There are also research labs in Haifa, Israel; Tokyo, Japan; Beijing, China; and New Delhi, India. The first three laboratories noted here employ 1,000, 800, and 220 people, respectively, while the other five laboratories each employ 200 workers. IBM Zurich has three departments: Science and Technology (famous for the number of Nobel prizes awarded), Communication Systems, and Applied Computer Science (formally IT Solutions). The two latter departments comprise the major part of the Zurich operation.

SYNOPSIS

Mr. Martin Hug and Dr. Pierre Chevillat greeted the WTEC panel. After the welcome and presentation of the March 15 Workshop summary by the visiting panelists (T. Itoh, L. Katehi, W. Stark, and D. Friday), IBM researchers made four presentations and one presentation/demonstration. The first two presentations and the presentation/demonstration came from the Communication Systems Department and are more engineering oriented. They are (1) "Mobile ATM" by Doug Dykeman, Manager of IP and ATM Networking, and (2) "Short-Range Radio Communication, HomeRF vs. Bluetooth" by Dietrich Maiwald, "Wireless Communication Systems," and (3) "Infrared Technology" (Short Lecture and Demostration) by Walter Hirt, Wireless Communication systems. The remaining two were from Applied Computer Science Department. They are (4) "'DEAPspace' Short-Range Wireless Communication" by Dirk Husemann, IT Solutions, and (5) "Wireless Application Protocol (WAP)" by Carl Binding.

Fairly extensive discussions on the role of university research and on technical subjects have taken place during the technical sessions. The presentations are mostly software oriented. Little description was given on hardware as it is outside of the charter and operation of these departments and are in some cases worked out at other facilities of IBM. The wireless subjects discussed were heavily oriented to data and computers.

MOBILE ATM

This project is for development of a mobile network integrated with a fixed infrastructure and is for aircraft, ships, and large ground vehicles. Uninterrupted operation is the goal while mobility is hidden from the users. Key protocols are ATM and IP for voice and data in the range of 0 ~100 kbps. This is a mobile ad-hoc (reconfigurable) network.

A new protocol called PNNI was introduced. PNNI routing has been accomplished while PNNI signaling is still under investigation. ATM Forum Standardization is carried out, and the prototype implementation is in progress with U.S. Navy through IBM's U.S. operation. The Federated Battle Lab of the U.S. DoD (Army, Navy, and Air Force) and NATO are responsible for implementing the prototype, and a demonstration is planned for September 1999.

Mobile IP, integration of IP on mobile ATM, and a new protocol for the future were discussed. The problems to be addressed are Routing (ATM, IP) and Re-routing (ATM). In the future, voice needs to be prioritized. Two problems that emerged from the discussions are the fading effect and frequency mobility (jamming in a military environment).

Short Range Radio (HomeRF vs. Bluetooth)

Because of the evolution of consumer electronics devices, connectivity is now a problem. Items in this category include digital broadband (ISDN, LMDS, etc.), cellular phones, and PCCS in a changing life style. Interconnectivity should be built in, not created using many phone lines. The key to acceptance by the customer is that these devices be made "easy, affordable and standard."

That is, the connection is interactive wireless without new wires. For Laptop and PDA, mobility is important. For the short-range format, Cordless (DECT) and Radio LAN, 2Mbps, 2.4 GHz including Hyperlan 1 (5.2 GHz, 10 Mbps) and Hyperlan 2 (5.2 GHz, 25 Mbps), are examples although simple infrared LAN has a problem in diffusion and shadowing by wall so that this can be used for line of sight only.

The following initiatives, HomeRF and Bluetooth, must be considered:

- HomeRF is in the unlicensed band. Ten companies are founding members, but the numbers extend to 87. HomeRF is based on DECT frequency hopping, IEEE 802.11 at 2.4 GHz ISM band, 1.2 Mbps frequency hopping, 100 mW, range of up to 50 m.
- Bluetooth is a project started by five companies. Membership has expanded to 612. Specifications are not firm, but a product was to appear in 1999. This system is based on a master/slave operation at 2.4 GHz, 1 Mbps (1600 frequency hops). A single chip implementation is expected to cost less than $20. Ad hoc network capability will include up to three voice and seven data links. This architecture involves the replacement of cable, not a network. Applications include cable replacement, data access point, and personal ad-hoc networks.

HomeRF is a networking project, but Bluetooth is for people on the move. The RF section was worked out at Yorktown. Future versions may use 5 GHz.

INFRARED TECHNOLOGY

IBM is working on advanced infrared wireless (AIr). Although similar physically to a TV remote control, AIr requires wide-angle (360°) coverage and long distance (10 m) data communication of 250 kbps to 4 Mbps with an LED of 900 nm wavelength. An experimental demonstration was provided during the WTEC visit.

DEAPSPACE SHORT RANGE WIRELESS

This is a software project and the acronym came from Distributed Embedded Application Platform. The objective is to connect nomadic and pervasive devices through transient ad-hoc and proximity-based network for short-range (less than 10 m) applications. There is no master-slave arrangement but rather the devices are allowed to talk to each other. The device characteristics are embedded into the microcontroller. There is no central node. Challenges for this software development are a description of services, flexibility and extensibility, simple process, and scalability. Currently, IBM has been working on simulation for transient ad-hoc networks and primitive test beds. Some of the competition is SUN's Jini, Microsoft's Universal Plug and Play, and Xerox's PARC's UbiHome.

Support of Pervasive Application and Devices (Wireless Application Protocol or WAP)

This is an effort to develop an emerging industry standard for Internet style context to mobile users. Currently, 90 members are helping to develop such a standard. An example is EasySabre (airline reservation system with Web-like operation) where software translates html to WAP.

CONCLUSIONS

In the opinion of several WTEC panel members, this location understood the panel's objectives most fully. IBM members, particularly the host, Dr. Chevillat, indicated their desires that the academy play an increased role in future oriented, often non-targeted research because most companies are decreasing research operations.

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White Paper "IBM Mobile ATM Networking Technology Overview." Version 2, August 1998.

Gfeller, F., and W. Hirt. 1998. "A robust wireless infrared system with channel reciprocity." *IEEE Communications Magazine* 36 (12).

Site: **Institute of Mobile and Satellite Communication Techniques (IMST)**
(German name) Institut fur Mobil- Und Satellitenfunktechnik GmbH
Carl-Friedrich-Gauss Strasse2
D-47475 kamp-Lintfort
Germany

Date Visited: 26 April 1999

WTEC Attendees: Dennis Friday (report author), T. Itoh, L. Katehi, R. Pickholtz

Hosts: Prof. Dr. Ingo Wolff, President, IMST and Rector, Duisburg University
Dr.-Ing. Mattthias Rittweger, Head of Department, RF Circuits and Systems
Dipl.-Ing. Johannes Borkes, Head of Department, Integrated Circuits and Systems
Dr. Ing. Dirk Heberling, Head of Department, Antennas
Will Chr. Will Hildering, Head of Department, Systems

BACKGROUND

IMST provides central engineering, test, and development resources for the wireless, telecommunications, and information technology industries. Customers include almost all of the major European wireless and telecommunication companies as well as companies throughout the Far East and Pacific, and Israel. The intellectual resources at IMST include expertise in both the systems and the hardware aspects of communications and information networks with a special focus on mobile wireless technology, both terrestrial and satellite-based. Its wide-ranging technical programs include component and systems engineering design, theoretical and experimental analyses, and special test and measurement services.

IMST President, Prof. Dr. Wolff, graciously served as the WTEC panel's host. The people it primarily interacted with were the IMST equivalent of the board of directors, which included Dr. Wolff and all four Department Heads. Dr. Wolff presented an overview of IMST, its history, its funding profile, its organizational structure, its technical programs, its staff profile, its customers, and its goals. His presentation was followed by more program-specific presentations by two of the four Department Heads. They talked about wireless systems architectures, RF hardware design and performance, and antennas for wireless applications.

The formal presentations were efficient summaries of the relevant IMST programs, and were enriched with off-the-viewgraph insights, peripheral discussions, and open and informative replies to the many questions from the WTEC team. The two-way interaction was intense and they adapted their agenda accordingly, but there was much more to discuss than the panel had time for, constrained by the need to travel from and to Frankfurt that day. Two of the department heads, with programs of interest to panel members did not give formal presentations because of limited time, however they did participate in the discussions, and the panel was given a condensed but comprehensive tour of the IMST laboratory facilities. Overall, the visit was very productive.

IMST, THE CORPORATE MISSION, HISTORY, AND ORGANIZATION

IMST management referred to the organization as a workbench facility for the wireless telecommunication and information technology industries. Special focus is on mobile and microwave communications techniques for industrial applications, and much of the work is related to technology development and evaluation for next-generation personal cellular/mobile communications hardware and systems. Their economic niche is the gap between relevant cutting-edge research and industrial product development. IMST helps companies bridge this gap by partnering with industry and performing the generic research and engineering development work necessary to accelerate product development. This effort in turn reduces the risk to industry in new commercial ventures. In addition to its primary role as a gateway between research and commercialization, IMST provides a broad range of expert technical services to industry, performs measurements to characterize antennas and other components, develops and carries out specialized training programs for industry, designs and fabricates special prototype hardware and software products for industry, and even carries out market research studies for new systems.

The institute is a private, non-profit corporation (designated GmbH in German). The laws governing a non-profit corporation in Germany are different from those in the United States. Most significant is the fact that if a German company declares itself non-profit, at least 50% of its income must come from the government, or it will not be recognized as a non-profit organization and be taxed as a for-profit company. However, IMST, due to its special role as both a national resource and a key facility that will help the Duisberg region attract high technology industries to compensate for their declining coal and steel industries, receives special dispensation from this requirement. The IMST mission is to serve industry and to derive most of its funding from the private sector. As a result of rapid growth in only a few years, and the excellent reputation acquired, approximately 80% of funding comes from the private sector, and 20% from publicly-funded R&D projects. Without special treatment as a non-profit company, IMST's programs would suffer financially. Otherwise, IMST pays taxes like any other company. The success of IMST can be measured by steady growth ever since it was formed, to over DM10 million of business in 1999.

Dr. Wolff told us that he and the four other managers present at the meeting, and the Vice President, assume all the technical and financial responsibilities for the operation of IMST. They pointed out that, unlike in the United States, the person who carries out all the legal work for the corporation is also an engineer by training. Professor Dr. Ingo Wolff's commitment of time was especially significant since the panel learned that, in addition to his position as President of IMST, he had recently been appointed Rector of Duisburg University (equivalent to chancellor of a university in the United States) and was embarking on a major restructuring within the university.

The IMST laboratories are located on a rural 10,000 m^2 site a few kilometers across the Rhine from Duisburg. The buildings contain 4,500 m^2 of space, of which 1,500 m^2 is laboratory space. The laboratory space includes a 300 m^2 clean room and several electromagnetic anechoic chamber facilities for antenna characterizations, electromagnetic compatibility measurements, and related wireless technology experiments. The building cost was DM12 million, and the total investment was DM17.5 million. Construction began in 1992, and the institute began operation in January 1993. IMST presently has 87 employees from 15 countries, including 68 engineers and scientists. IMST also maintains a close working relationship with the University of Duisburg, and a total of 40 students work at IMST from there and from other universities. Staff size has been approximately constant since early 1996.

The organizational structure is straightforward, consisting of an administrative branch and four departments. Dr. Peter Waldow, Vice President of IMST, is responsible for operation of the company. He has responsibility for central services, marketing, legal issues, technology transfer and intellectual property, quality assurance, finances, and general administration. The four departments are Systems, Integrated Circuits and Systems, RF Circuits and Systems, and Antennas & Electromagnetic Compatibility (EMC). Overviews were only given by the Systems and the Antennas and EMC Department Heads. The others were present throughout the meeting and participated in discussions.

The Systems Department, under the direction of Will Hildering, is responsible for communications networks and systems, satellite systems, wave propagation, mobile systems, signal processing, and digital electronics. The Antennas and EMC Department, under Dr. D. Heberling, is responsible for antenna performance and characterization, EMC analysis and evaluation, and the interactions of human systems with electromagnetic fields and wireless equipment. The RF Circuits and Systems Department, under Dr. M. Rittweger, is responsible for electromagnetic modeling and simulation of devices and circuits, the design and development of radio frequency (RF) circuits, modules, and printed wiring boards, and hybrid microelectronics. The Integrated Circuits and Systems Department, under Dr. J. J. Borkes, is responsible for applications specific integrated circuits (ASICs), integrated communications circuits, RF circuits, and related measurement techniques. Only two of the departments provided overviews, and the division of responsibilities was not clear where there appeared to be an overlap.

IMST leverages its resources by partnering with industry, standards, and professional organizations. These include ETSI, the UMTS Forum, the UMTS Development Partnership, ITG, FGF, IMEC, IMAPS, the University of Duisburg, and other groups. They also are ISO 9000 accredited and maintain an ISO 9001 Quality System. They market worldwide by partnering with international technical marketing agencies. Customers include many of the key telecommunications companies in Europe and Asia.

IMST, THE TECHNICAL PROGRAMS

IMST is active in a broad range of technical programs focused on both the physical and architectural/algorithmic aspects of wireless systems communications. Emphasis is on mobile communications and 3rd Generation (3G) wireless technology. The role IMST plays in enhancing the development and competitiveness of European and Asian wireless technology is significant. IMST serves as a central laboratory resource for independent technology development, for reliable measurements, for impartial performance evaluations, and for industry training and leadership. The main technical programs will be summarized in the following paragraphs.

Antennas and Antenna Characterizations

Antenna design and prototyping is one of the services provided by IMST. The activity in this area ranges from pure research for maintaining cutting-edge competence, to, for-contract, application designs, the latter comprising mainly mobile radio antennas and microwave satellite communications antennas. Although antenna design was not a strong component of the briefings, the WTEC study team did visit some of the related laboratories and see some prototypes. The antenna design challenges for handheld units were for innovative designs fully integrated with the geometry and space-location constraints of the handset. The designs also incorporated information gleaned from antenna-human interaction studies. There was also some work on integrated antenna-RF front ends. In addition to their design expertise, IMST researchers are very strong in providing antenna characterization support for industry. Their antenna measurement facilities are of high quality and used for characterizing a broad range of antennas for both terrestrial and satellite communications. One is an indoor facility and the other is an outdoor range. The WTEC panel only visited the indoor range due to time limitations, but received a description of the outdoor range and viewed it from a distance.

The indoor antenna measurement laboratory is a totally shielded 8 x 12 x 5.5 meter facility used in two modes, as a near-field facility and as a far-field facility. It is lined with pyramidal absorber and has a useable frequency range from 400 MHz as a near-field facility (800 MHz as a far-field facility) to 50 GHz. The measurement apparatus is a 2.5 x 2.5 meter automated planar near-field scanner procured commercially. As a near-field facility it is used primarily for determining pattern, polarization, and gain properties of high gain antennas used in satellite or long terrestrial links; and as a far-field facility, it is used for pattern and polarization characterizations of electrically small, high frequency, low gain antennas used in hand-portable or vehicular-mobile telecommunications applications.

The outdoor facility is a standard far-field range with a 110 m separation and a 23 m source tower. The main applications are for characterizing pattern and polarization of physically larger and heavier antennas ranging from low frequency antennas down to 50 MHz, to high frequency, high gain antennas up to 18 GHz. There is also a mobile tower and a satellite-to-ground capability when longer baselines are required.

Studies of Human-Antenna Interactions

IMST also has an antenna program that focuses on the effects of the human user on the handset antenna pattern, RF front-end and propagation, and also on the EM field patterns in the human body, particularly the head. The latter is for evaluating and designing for compliance with European EM exposure regulations. IMST also has a well developed experimental and theoretical program for developing complete and realistic models of the electromagnetic fields inside the human body and around the human user of a mobile telephone handset, as compared to the handset in isolation. The research includes developing accurate electromagnetically equivalent models of the typical human body at frequencies of interest and performing accurate measurements of field patterns.

IMST has unique experimental facilities dedicated to modeling the effects of the human body on air link performance. This work has several aspects. One is directed toward a standard measurement configuration for comparing the performance of different handheld phones. A standard human replica artifact was developed by combining simple geometric forms into a circularly symmetric saline-filled standard human researchers call Charlie. The performance of different handheld units, both prototype and commercial, are studied and compared by placing them adjacent to Charlie's head and rotating Charlie in an anechoic chamber containing a receiving antenna that can scan vertically. The frequency range for this work is 10 MHz to 6 GHz. IMST offers a service for determining realistic radiation characteristics and specific absorption rates in the human body based on this model and is working with ETSI to standardize the procedure.

Researchers also developed another facility for performing measurements to determine human-body effects on antenna and system performance and for use in modeling. The apparatus consists of a basin with a surface contour corresponding to the right half of the human torso, oriented vertically. The basin may then be filled with fluids that mimic the approximate electromagnetic properties of the human body at various frequencies. If a handset is placed under the basin near the ear, then this design enables the field patterns to be measured inside the head, or elsewhere in the body for biological studies and for modeling effects on antenna performance. A precision computer controlled 6-axis robotic arm is used for precisely positioning electromagnetic field probes on a spatial grid of points inside the fluid medium. The probes can measure both the electric and magnetic near-fields of the transmitting antenna over a frequency range of 10 MHz to 3 GHz in fluid and up to 6 GHz in air. This facility is called the Dosimetric Assessment System, or DASY. This facility is used for compliance tests for exposure limits as well as for optimizing new antenna designs. Software modeling services are provided that link with these measurements.

Environmental Reliability Validation

IMST also has a range of peripheral services for evaluating the reliability of the designs in normal use. It provides a sort of one-stop shopping lab for its customers' essential needs. There are electrodynamic shaker facilities and a time-variable-temperature chamber for testing components and systems under vibrational and thermal stress. Parameters such as voltage, current, frequency, power, spectrum (to 40 GHz), and bit error rate are monitored during the environmental stress test to assess performance. Poor reliability can negate any superior electrical performance in a commercial wireless product. The facilities are set up specifically to test communications systems with coax and wave-guide connections to the unit under test.

Software Development and Services for Wireless Design and Modeling

IMST also performs the research and the software development necessary to produce and market a collection of software packages for wireless design and modeling. One of the software products and services is a full wave 3D FDTD PC program for solving Maxwell's equations. Called Empire, it has special wireless-design oriented features for modeling RF microcircuitry as well as antenna performance and human body effects. There is also a software package for nonlinear modeling of FETs called TOPAS that has been incorporated into HP's EEsof design and simulation software package. MEDEA is a system for the design of Silicon ICs incorporating thermal and electromagnetic constraints, while improving reliability and reducing costs.

Coplan is a new design and simulation tool for design of coplanar waveguide (CPW) MMICs. It is integrated with HPs EEsof and the user can perform simulations and optimization for GaAs designs up to 67 GHz. Customers can purchase the packages, but IMST staff can also provide solutions for the customer, as well as use the software for internal research.

Characterization of Active Wireless Components

IMST provides measurement services for a wide range of wireless and microwave technologies. IMST has well-developed laboratory facilities for characterization of devices, circuits, and components. The different measurement systems are used for internal research and development projects and are also used to provide complete measurement services for external customers. Some of the systems and related software are offered for sale. The total program provides a wide variety of measurement capabilities and services for both linear and nonlinear characterizations.

The following is a summary of capabilities:

- fundamental linear characterizations
- scattering parameters: two- and three-port, 40 MHz to 110 GHz
- spectrum analysis
- thermal noise: 1 to 26.5 GHz
- noise figure: 100 MHz to 26.5 GHz
- phase noise

IMST has developed its own methodology and instrumentation for characterizing various nonlinear properties of devices, circuits, and systems for one-port, two-port, and three-port configurations. Some of these capabilities are not commonly available and may incorporate unique analysis methods. This is also an active research program for new techniques. These methods are available for on-wafer (coplanar geometry), microstrip, and coaxial lines. Unfortunately we did not see their microstrip measurement techniques.

The following are some of the specifications for harmonics and intermodulation products:

- load pull: 410 MHz to 110 Ghz, >80 dB dynamic range, > 10 W
- power sweep: up to 110 Ghz, > 10 W, VNA analysis

Electromagnetic Compatibility Design and Assessment

IMST has extensive expertise in both modeling and measurements for characterizing electromagnetic compatibility of radio/wireless products. Modeling software and experimental facilities include an anechoic chamber. These capabilities are used to perform research, as well as to provide customers with data and with test services to determine whether product emissions satisfy U.S., international, and E.U. trade compliance regulations. IMST is on the U.S. FCC list of approved facilities for certification of specific absorption rate for handheld products headed for the U.S. market. EMC compliance of all electronics/wireless products and official recognition of test facilities are significant issues in wireless for the global market.

Design and Prototyping

IMST provides services for design and prototyping of RF devices and RF front-ends. Excellent RF design software is available, both in-house developed and commercially available software. Capabilities include CAD, simulation, optimization, and EM field simulation for RFICs, MMICs, ASICs, hybrids, and communication systems. It has complete clean room and GaAs fabrication facilities (300 sq. m - class 100 to 10,000) for developing prototype devices and systems. IMST is very active in this area. Some of the projects include the following:

- new, more efficient devices and microcircuit geometries (layered, etc.)
- RF front ends for handsets
- RF modules for communications transcievers
- complete radio systems including a software radio that was really an RF front end with a software reconfigurable digital/systems section

Overall this effort comprised a significant portion of the activity, and IMST demonstrated a successful history of having designed and developed the RF sections, and other components, for many successful radio products manufactured by well-known international electronics/wireless companies in both Asia and Europe.

SUMMARY/CONCLUSIONS

IMST is, by its mission, and the work it engages in, forward looking. The projects all reflect the cutting-edge technology for commercial products. IMST's brief history combined with its growth and successes speaks for its capabilities. In short, IMST appears to be well embedded in the enabling technologies underlying the worldwide wireless industry, and its management and technical staff are competent and in a good position to observe major trends and assess emerging technologies. Programs address important problems in the wireless industry. For example, in addition to GSM refinements, IMST is active in UMTS, DECT, and general 3G and 4G issues. The current focus, with the exception of satellite technology, is almost totally terrestrial, portable, and mobile.

IMST sees the wireless industry evolving as essentially mobile technology embedded in adaptive architectures and believes that the mobile economy will expand astronomically. IMST researchers stated that Europe is not interested in LMDS for Europe, just as a possible product to sell abroad wherever it is marketable. As a result, it is not receiving much attention and no energy is being expended in this area with respect to standards activities or R&D as happened on GSM or is now happening on UMTS. No one believes that a market exists in western Europe for LMDS systems or services in western Europe, because there is already a hard-wired infrastructure that will meet all European needs. IMST researchers also aren't convinced that the performance of broadband wireless systems at 30 MHz frequencies will be superior to wired broadband systems or to advanced mobile systems.

The broad but focused range of programs covers virtually all hardware aspects of wireless. Many of the designs exhibited were straightforward but well executed. Other designs reflected innovation and experimentation. The centralized wireless-focused design, device prototyping, software services, test and measurement services, and products provided are clearly an asset to customers, and enhance competitiveness. While the WTEC panel saw no great departures from conventional technology, IMST is a key facility and a lab to watch. Two examples of programs that best reflect cutting edge thinking and planning are the nonlinear circuit and device modeling and characterization project and the elaborate theoretical and experimental program to assess the interactions of the handset antenna and the human user and model the effects on propagation, RF circuitry, and field levels in the body. The significance of these projects is the contributions they will make to aspects of wireless design that are presently only partially characterized. Devices in handheld units are always operating in or near saturation to optimize battery life and the design process to optimize the nonlinear behavior is a black art. Propagation paths can degrade 3 to 5 dB when the typical GSM phone is placed near the head, and other wireless units have exhibited 8 to 10 dB degradation in the hands of users. These are important programs and important wireless issues.

Site: **Nokia**
P.O. Box 45
00211 Helsinki
Finland

Date Visited: 27 April 1999

WTEC Attendees: W. Stark (report author), N. Moayeri, R. Rao, J. Winters, A. Ephremides, L. Young, M. Iskander

Hosts: Heikki Huomo, Vice President, Research and Technology Product Creation
Yrjo Neuvo
Antti Yla-Jaaski

BACKGROUND

Nokia is a leading manufacturer of wireless communication equipment, including cellular phones and base stations. Nokia has research facilities across the world including Helsinki and Richardson, Texas. Nokia revenue has been increasing at a rate of roughly 30-35% per year for the last 15 years. Nokia has led the industry in marketing phones. Nokia has hired outside companies for research including TI for research on solid state devices. Nokia spends about 8% of sales on research and development. Not all of this was internal research as Nokia sponsors research by other companies and universities. Nokia has 44,543 employees in 45 different countries with research centers in four countries.

The meeting at Nokia began with a fairly large group (around 30) of engineers, product developers. These engineers were participating in a continuing education program whereby Nokia brings in experts from universities together with Nokia engineers. Nokia has a formal mentoring type of program for engineers in order to continue their professional development. This may be quite unique compared to many other companies.

The meeting had several parts. First, Prof. Ephremides, chair of the WTEC panel, gave an overview of the goals of the study and sponsorship. Second, two members of the Nokia research staff, Hekki Huomo and Antti Yla-Jaaski made presentations, followed by discussion and questions from the panelists. After this, a lunch meeting with Hekki Huomo and Antti Yla-Jaaski was held, where further discussion regarding research took place.

At the first part of the meeting, research areas of interest to the panel relevant to wireless communications were discussed. Dr. Neuvo of Nokia added display technology and EMC effects to the list of important research areas.

Dr. Huomo discussed the generations of wireless systems from first generation AMPS/NMT to third generation, from analog modulation to digital modulation. The second to third generation is from mainly voice to a combination of data and voice along with packet oriented services.

He also discussed wireless computing where the data rate is from 2-155 Mbps, the carrier frequency is much higher (2GHz and above), and the service is best effort. The architecture of the network is also not celluar/ hierarchical. The future drivers for wireless communication include multimedia communications. A new way of presenting information is needed. The Internet was a success because of available content with intuitive access. A means of differentiating between personal data and work-related data was also discussed as a future goal. Data would be gathered, in this scenario, depending on whether the user is at home or in the office.

It was suggested that service and protocols will have more influence in the future and that the driver of technologies will be service and application protocols and not more capacity (as is the current driver).

The following list of technologies needed to achieve these applications was suggested:

- board assembly/packaging
- chip scale packaging
- RF passive integration with MCM-D
- flip chip technology
- filer integration with BAW
- CMOS RF
- enhanced digital and analog ASICs (Productivity in ASIC design must grow so that a Pentium can be designed in one man-year)
- product architectures
- mechanics
- user interface
- external interfaces
- antennas
- battery and energy management
- software defined radios (SWDR)
- technology to create multimode and multiband radios
- technology to create mobile multimedia platforms
- radios that are flexible and easily configurable
- Software or quick design cycles
- radios based on virtual components

SUMMARY

Nokia is a very product oriented company with a heavy emphasis on marketing cellular phones. It has become an international company, leading the industry in cellular phones, and is focusing on systems integration. Nokia has a unique system for mentoring employees with university faculty. The research drivers for future wireless communications include high speed, high frequency transmission of multimedia data, and personalizing data retrieval. The research topics needed to achieve this include board assembly/packaging, chip scale packaging, RF passive integration with MCM-D, flip chip technology, filer integration with BAW, CMOS RF, enhanced digital and analog ASICs, user interfaces, external interfaces, antennas, and battery and energy management.

Site: **Philips Research Laboratories**
Prof. Holstaan 4
5656 AA Eindhoven
The Netherlands
http://www.research.philips.com/generalinfo/laboratories/netherlands.html

Date Visited: 28 April 1999

WTEC Attendees: J. Winters (report author), M. Iskander, N. Moayeri, R. Rao, W. Stark, L. Young

Hosts: Dr. C.P.M.J. (Stan) Baggen, Research Fellow, Digital Signal Processing
Dr. H.A. (Rick) Harwig, Director, Electronic Systems
Dr. Peter Baltus, Research Scientist, Integrated Transceivers
Dr. Marcel J.M. Pelgrom, Department Head, Mixed Signal Circuits and Systems
Dr. Paul Kaufholz, Research Scientist, User-System Interaction Technology
Prof. Dr. J.W. (Hans) Hofstraat, Department Head, Polymers & Organic Chemistry
Dr. Jean-Paul M.G. Linnartz, Senior Scientist, Broadband Communications &Video Systems
Dr. Carel-Jan L. van Driel, Department Head, Digital Signal Processing Group
Dr. C.R. de Graaf, Senior System Architect, Compact Personal Communicator

BACKGROUND

Royal Philips Electronics is one of the world's biggest electronics companies and Europe's largest, with sales of $33.9 billion in 1998. Founded in 1891 in Eindhoven, the Netherlands, it is a global leader in color television sets, lighting, electric razors, color picture tubes for televisions and monitors, and one-chip TV products. Its 233,700 employees, in more than 60 countries, are active in the areas of lighting, consumer electronics, domestic appliances, components, semiconductors, medical systems, business electronics, and IT services. The WTEC panel visited Philips Research Laboratories in Eindhoven.

Philips Research was started in 1914, and currently has 3,000 employees worldwide, with 1,700 employees in the headquarters in Eindhoven. The major research areas are materials (29%), electronics (15%), and software, systems and devices with a budget of $600 million for research out of an R&D budget of $2.2 billion. Over 60,000 patents have been issued to Philips Research, which is the backbone for corporate technology strategy.

Rick Harwig, Director of Electronic Systems, gave an overview of the work at Philips Research Laboratories, describing the various projects and achievements that have been made. He noted that there are currently 150-200 people involved in wireless, and the number is expanding at a slow rate, due to the lack of qualified candidates.

RESEARCH AND DEVELOPMENT ACTIVITIES

The panel heard six technical talks on research projects at Philips Research Laboratories. Peter Baltus, Research Scientist, discussed RF front ends for wireless communications. He first noted the trend to higher data rates and frequencies, with outdoors up to 5 GHz and indoors greater than 10 GHz for higher bandwidths. He saw the main issues for RF electronics as lower cost, low weight and volume, and long talk/standby time.

Noting that the RF front end consumes more than 50% of the total power in a handset and currently uses more than 20 external components, he stated that the main challenges are the integration of the transmitter, integration of the antenna interface, multiband/multimode operation, and A/D technology. This includes eliminating external impedance matching circuits and duplexer components, along with advanced antenna diversity. Since Philips is primarily involved in handsets (e.g., in DECT), the main emphasis of the discussion was on techniques for handsets. Baltus described the Philips scanning dual-antenna handset, noting the need for better radio channel characterization. He then stated that one method for power reduction was the elimination of the substrate to get around parasitics' problems and discussed Philips Silicon-on-Anything technology and how this technology could be used to integrate high Q resonators.

Marcel Pelgrom, Department Head, Mixed Signal Circuits and Systems, discussed A/D conversion and power management for future digital systems. He noted the tradeoff of resolution versus bandwidth in A/D converters, which results in large power at high resolution and bandwidth. The challenge is to achieve high-speed/resolution A/Ds so that multichannel transceivers can be integrated for lower cost. The trend in higher resolution/bandwidth A/D converters was seen to be continuing for another 6 to 10 years, with 3 orders of magnitude improvement still left. This should result in practical A/D converters for WCDMA in 4-5 years. In power management, the trend in increasing energy per weight and size was seen through the evolution of batteries from NiCd to Li-ion to Li-poly to future unknown materials.

Interestingly, one of the best research areas for power management was seen to be in better power management software, including improved protocols. It was stated, however, as in the previous talk, that RF power will dominate over software power, and additional digital signal processing (DSP) will not compensate for poor A/Ds. Thus, he felt that long-term research should emphasize RF and packaging research over DSP/software improvement, although software improvement can have some effect on RF design.

Paul Kaufholz, Research Scientist, User-System Interaction Technology, discussed voice control in the living room. He noted that with more wireless devices in the future, there would be a growing need for better user interfaces to these devices, in particular, voice control. The key challenges were seen to be acoustic speech recognition and echo cancellation.

Hans Hofstraat, Department Head, Polymers & Organic Chemistry, discussed polymers: new options for electronics. With polymers, the main advantage is very low cost. Currently, polymers are used for LEDs today, and he demonstrated such a device. In 2-3 years they should be used in electronics, and in 5-10 years in batteries. This has the potential to reduce costs to the point that disposable wireless phones may be feasible. However, substantial research is still needed, with particular emphasis on multidisciplinary research, which is a challenge.

Jean-Paul Linnartz, Senior Scientist, Broadband Communications & Video Systems, discussed wireless system issues. In particular, he felt that as higher data rates stretched the limits of bandwidth, wireless data systems would evolve to a frequency reuse of 1 (frequency reuse in every cell). With this reuse in combination with dynamic channel assignment, research was needed into channel assignment with data packets, i.e., dynamic packet assignment. He also stated that there should not be one system to handle both short messages and high data rate services such as HDTV, but a combination of systems. Furthermore, for higher data rate systems the trend may be away from spread spectrum type of systems.

C.R. de Graaf, Senior System Architect, Compact Personal Communicator, discussed ultrawide bandwidth systems and briefly described the possibility of placing the transceiver on a chip.

After the presentations by Philips, Ramesh Rao presented the results of our national workshop to a seminar group of about 50 Philips employees. There were discussions with the group covering the above areas, including discussions on ultrawide bandwidth systems.

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