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Exploration Programmes:
Corporate Technology Explores Future Telecommunications

EMC in the Networked World

Processors continue to get faster, smaller and cheaper. This is allowing a wireless revolution to take place: Transmitters will be installed everywhere, from laptop computers to PDAs, home appliances, and even in our clothing. All of these transmitters will compete for the scarce frequency resources leading to interference situations that will impair the reliability and quality of the services they will carry.
We have studied two important wireless systems, Bluetooth and Wireless LAN. We observed experimentally that severe degradation of the WLAN performance occurs in the presence of Bluetooth transmitters. Work is underway to create installation guidelines and countermeasures.

The "Electromagnetic & Environmental Effects" programme explores the electromagnetic compatibility (EMC) aspects of emerging telecommunication technologies and the biological effects of electromagnetic radiation.
With its Exploration Programmes, Corporate Technology is exploring telecommunication technologies and new service possibilities with a long-term view of 2–5 years. Further, the expertise built up in the course of this activity enables active support of business innovation projects.

Wireless systems will be used more and more often as new services are developed and as the devices and systems that carry them get cheaper. The "always-connected" vision is leading to an explosion in the number of wireless communication systems. The percentage of mobile telephone users has already increased beyond 50% in some Scandinavian countries and it is expected that the number of users world-wide will continue to grow unabated in the foreseeable future.

MARCOS RUBINSTEIN

Wireless personal area network systems, from which commercial devices are expected this year, will probably be deployed in most of our cellular telephones, PDAs, laptops and appliances before this decade is out and will allow enabled gadgets to establish, automatically, a network when within 10 m of each other.
Since all of these systems share the air interface, one might think that some form of frequency-spectrum management would be integrated into the standardisation to minimise interference problems. In reality, standardisation bodies and special interest groups have selected the unlicensed ISM bands (Industrial/Scientific/Medical equipment) for Bluetooth and Wireless LAN. The same band is used by a growing number of manufacturers to offer their own, non-standardised systems for applications such as video transmission, home networking switching circuits etc. This can potentially lead to interference situations that should be studied proactively if at least some level of peaceful coexistence of all the different systems is to be achieved.

Within a few years, we will all carry wearable computers which will be wirelessly connected to each other and to the World Wide Web. We will be increasingly dependent on the proper functioning of these devices to access banking, entertainment, and education services, and to make our payments. But these miniature transmitters are being developed disregarding the existence of the other systems. Can we guarantee that they will coexist peacefully, without disturbing each other?

A significant fraction of Swisscom's new services will be carried by wireless communication systems such as GSM, DECT, UMTS, Bluetooth and Wireless LAN. In fact, WLAN is starting to be used in office buildings to guarantee Intranet connectivity while on the move. In addition, mobile telephones, laptop computers, peripherals, and home appliances are expected to be equipped with Bluetooth transceivers in the next few years. Moreover, many other inexpensive, proprietary systems working in the same frequency

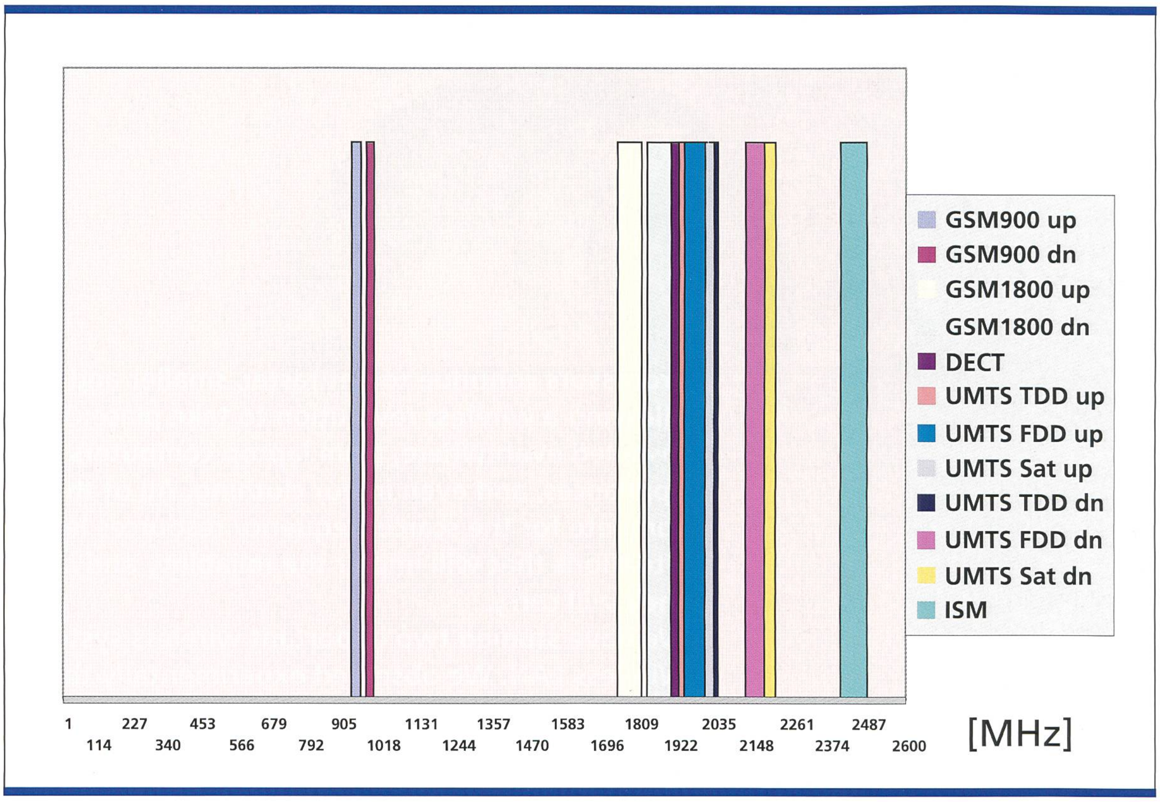

Fig. 1. Frequency allocation for GSM900, GSM1800, DECT, UMTS and ISM systems.

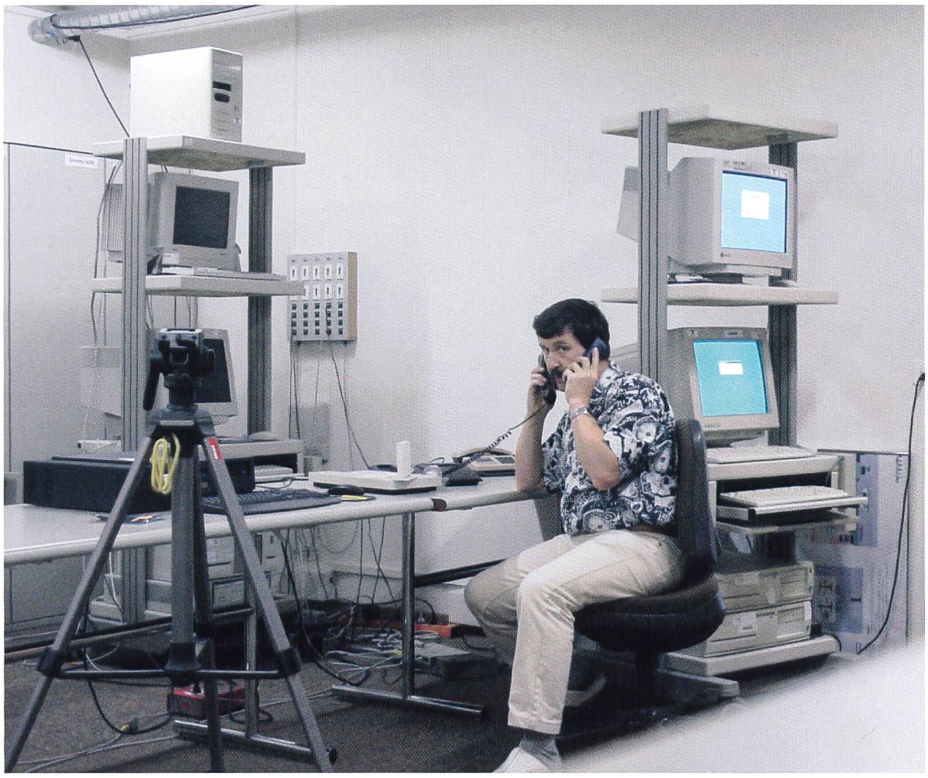

Fig. 2. Electromagnetic Effects Lab (eel).

band are becoming available to the general public (you can buy them in supermarkets), making interference situations inevitable.
The know-how and experience in EMC available at Corporate Technology helps Swisscom guarantee the best reliability and quality of service. The activities include consulting on technical and legal issues related to EMC problems. Exploratory work, such as that reported in this article, is done in the Exploration Programme "Electromagnetic and Environmental Effects".

Search for Interference Situations: EMC and Coexistence

Electromagnetic Compatibility (EMC) can be defined as the ability of an electronic system to work properly in its intended electromagnetic environment, without disturbing other systems. This includes not only the interference-free coexistence of two pieces of equipment but also the immunity of an apparatus to the effects of electrostatic discharges, lightning induced voltages etc.
Although some EMC problems are relatively easy to identify and to correct, many of them are not. Common examples of easily identifiable EMC problems are the noise heard on the fixed telephone when a nearby GSM phone is about to ring due to an incoming call or the noise heard on an FM car radio when the vehicle has stopped near the control circuitry of a traffic light. Other problems that often have an EMC origin but that are harder to identify as such are, e.g., an airbag that deploys unexpectedly under normal driving conditions or the slowness of an internet connection. Considering emerging technologies, most EMC problems are expected between radio systems. Such interference problems are referred to as "coexistence problems" and, due to their importance, we concentrate on them in this article.
To find potential interference conditions related to emerging wireless technologies, one looks for situations where two or more systems coexist in frequency, time, and space. Besides reviewing customer complaints and surveying the literature for reports of existing or potential problems, two methods are used by the Corporate Technology EMC team for the early detection of potential radio-to-radio EMC problems with an impact on Swisscom's business. These are briefly explained in the next two sections.

Method 1:
Frequency Allocation Analysis

A first indication of possible interference is given by the frequency band alloca-

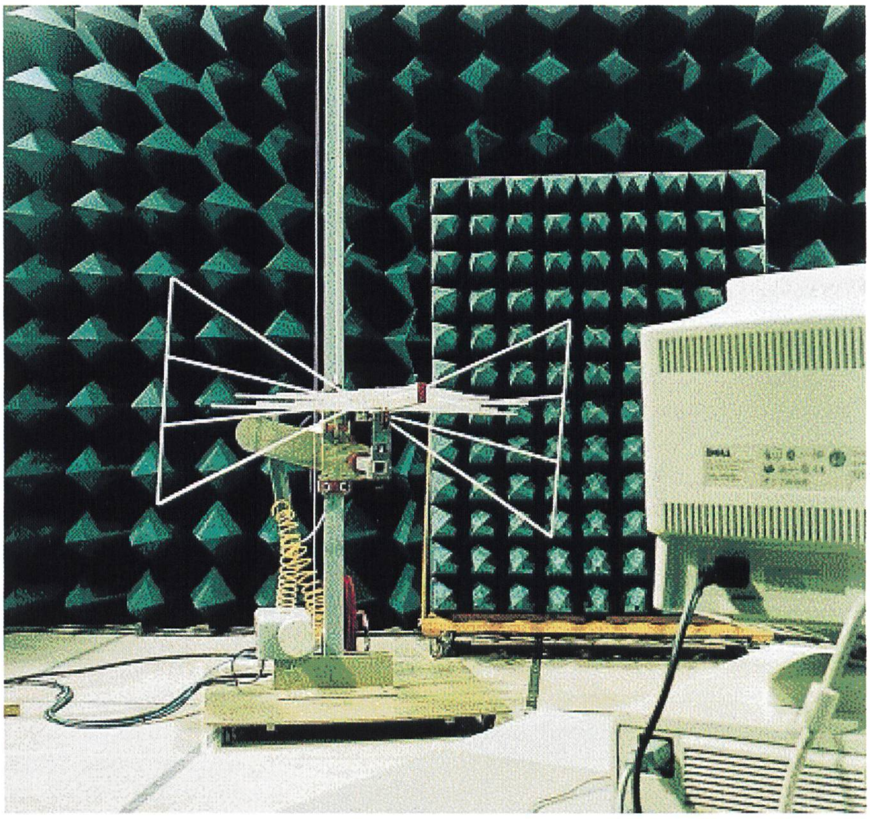

Fig. 3. The EMC test laboratory.

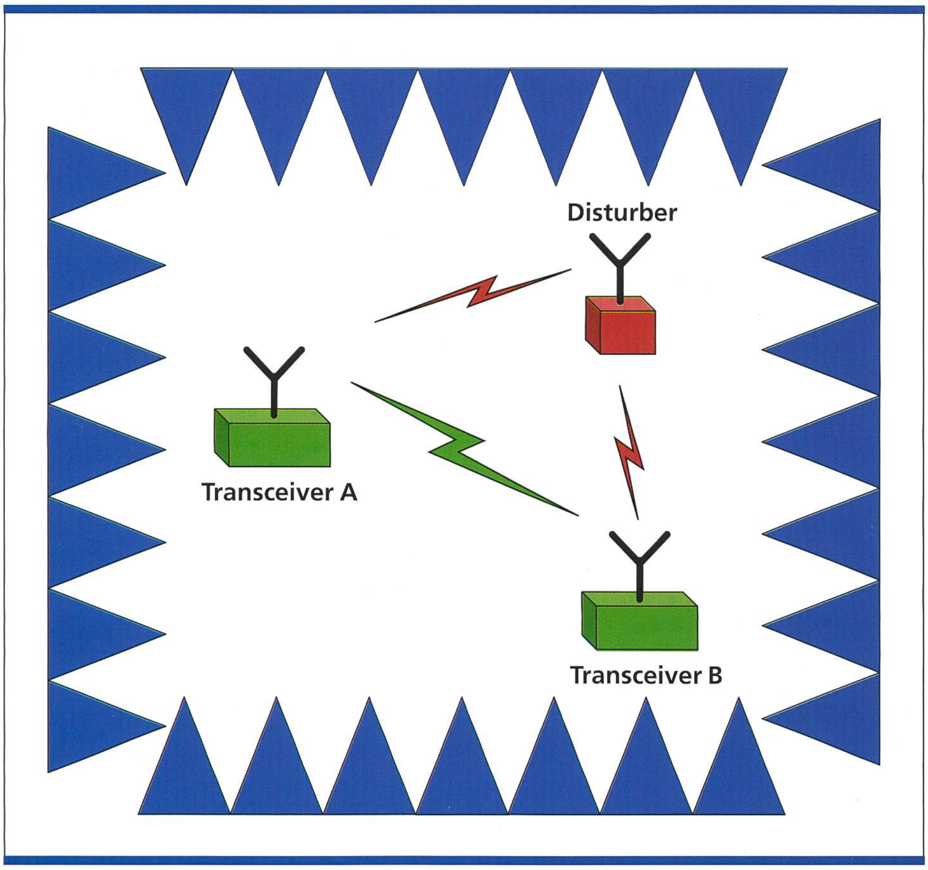

Fig. 4. Schematic top view of a test in the EMC laboratory.

tions of the different systems and their inter-modulation products (usually the 2nd and 3rd). It is important to note, however, that, even if the allocated frequencies or their harmonics overlap, this does not necessarily mean that the systems will interfere with one another. This is due to the fact that modern modulation and diversity techniques may allow systems to share the same frequency band without appreciably affecting each other. For this reason, potential inter-system interference problems need to be further examined by taking into account other system specifications, such as modulation, utilisation of spread spectrum technology etc.

The interfering frequency can be generated directly by one of the systems or through inter-modulation products in non-linear components. When the disturbing frequency lies within the frequency band of the disturbed system, one speaks of "in-band interference" or "co-channel interference". When interference occurs between systems that do not use the same frequency band but share poorly filtered stop-bands, it is called "out-of-band interference" or, if occurring at an adjacent channel, "adjacent channel interference".

A plot of the frequency allocations for the most important existing and emerging systems is shown in figure 1.

Analysis of in-band, out-of-band and inter-modulation products interference shows that problems are most likely to occur in the ISM band, where, as already mentioned, Bluetooth, WLAN and a growing number of proprietary video and data transmission systems operate.

Method 2: Direct Experimentation

Even if engineers use existing EMC standards to design systems which avoid interference, many electromagnetic compatibility problems are found only after the first prototypes are put in operation or after the first products are in the market. This has come to be known in the EMC field as the "surprise effect". One of its reasons is that compliance with international standards does not guarantee electromagnetic compatibility in all situations. In fact, standards constitute minimum requirements only that have been negotiated between manufacturers (who lobby for relaxed EMC requirements), and users and operators (who lobby for strict requirements).

It is therefore desirable to test systems in their intended environment before putting them into the market. This is not only important for manufacturers but also for Swisscom as a customer-oriented company and a system integrator.

Legally, it is the responsibility of the system integrator and not of the manufacturer of the individual systems to guarantee proper performance of an integrated system.

In order to detect, study and offer guidelines and countermeasures for possible EMC problems of importance to Swisscom, Corporate Technology has set up the Electromagnetic Effects Laboratory, known as "eel" (fig. 2). The eel laboratory is used to explore the electromagnetic interactions between systems that will be found in tomorrow's homes and offices. At present, the user of the lab can test the compatibility of a VDSL system, 2 Mbps and 11 Mbit/s WLANs, a commercially available video transmission system working in the ISM band, GSM, DECT, and other systems. Effects discovered in the lab include visual and sound effects of GSM on telephone sets, Video Link/WLAN interference and Bluetooth's effect on WLAN.

Analysis

Once EMC problems have been identified, they are analysed to propose economically viable countermeasures and/or installation guidelines. This is done through theoretical analysis supported by controlled experimental measurements.

The analysis of interference situations is complicated by the sophisticated modulation and automatic error-correction techniques applied in today's digital communication circuits. In fact, some of today's digital communication systems appear to function correctly even under harsh electromagnetic disturbance conditions. This is due to the fact that a given number of bit errors can be corrected automatically by appropriate coding. However, such systems may collapse abruptly when the interference source gets closer by just a few centimetres if the error correction protocol has been taken to its limit.

In order to achieve some level of reproducibility, measurements are generally carried out in an EMC test chamber. Such chambers are shielded rooms whose interior is lined with electromagnetic absorbers in the form of ferrite tiles and pyramidal foam pieces (fig. 3). The absorbers simulate an open area by min-

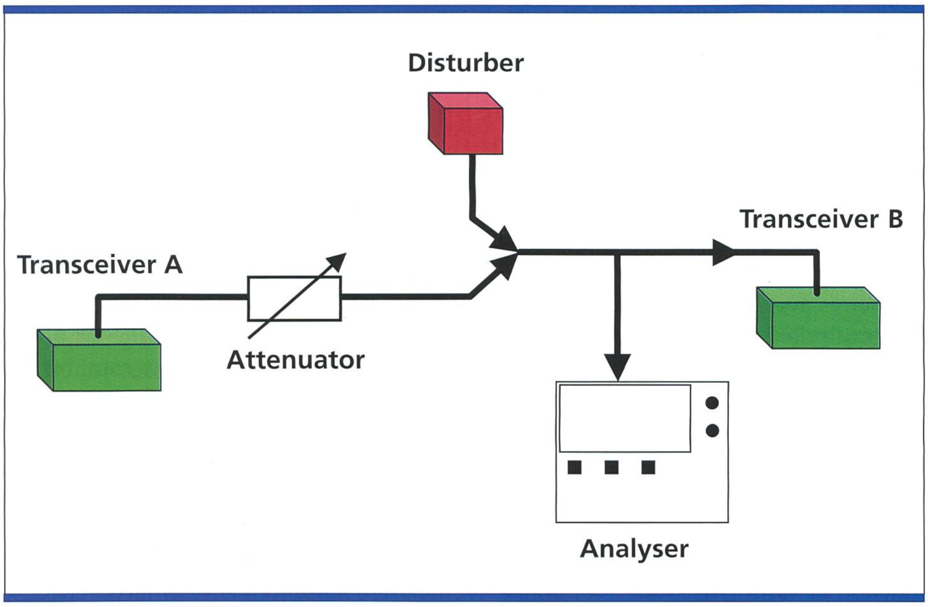

Fig. 5. Cable bound simulation of the EMC situation of figure 4. The attenuator simulates propagation loss.

imising electromagnetic reflections off the walls.

A top view of a typical experimental set-up is drawn schematically in figure 4. The dark blue cones represent the wall absorbers of the EMC test chamber. Inside the chamber, there is a potential victim under test (transceivers A and B) and a disturber.

The potential victim could be, for instance, a WLAN, in which case transceiver A represents an access point and transceiver B represents a mobile station (PC connected to the WLAN). The disturber may be a Bluetooth device, a video link, or other short range radio device.

The red arrows in the figure represent the interfering signals radiated by the disturber. Note that, as in real situations, the interfering signal affects both, transceivers A and B, which complicates the analysis of the measurement results. Additionally, it is difficult to simulate a sufficiently large dynamic range of propagation loss between the antennas in a well controlled manner. For analysis purposes and to improve flexibility, it is therefore convenient to study the effects of the disturber on each transceiver separately. To achieve this, cable bound measurements (described below) have been introduced.

Cable Bound Measurements

In cable bound measurements, the antenna path is replaced by a coaxial link, connecting both transceivers (fig. 5). Using a directive power combiner, the disturber is coupled to one of the transceivers only. The variable attenuator simulates path loss. An additional non-directive power combiner provides for precise measurement of the transceiver and disturber signals.

Results

The frequency band allocation analysis described above was applied to a number of wireless communication systems that will most likely carry Swisscom's services: GSM, UMTS, WLAN, DECT and Bluetooth. Although interference situations involving DECT, GSM and UMTS cannot be excluded, the devices that operate in the ISM band are by far the most likely sources and victims of interference, not only due to their operating in an unlicensed band, but also because they are the current candidates for ubiquitous computing and communications.

To test the systems in the ISM band experimentally, we installed the following equipment in the eel laboratory:

- Two WLAN systems (2 Mbit/s and 11 Mbit/s, respectively)
- A pair of prototype PCMCIA Bluetooth cards installed on two laptops
- A proprietary video link system

The Bluetooth prototype was obtained shortly before the writing of this article and it was not possible to carry out exhaustive tests with it yet. Except for the tests in the eel, all the Bluetooth results reported here were obtained by simulating the Bluetooth signals. The results concerning Bluetooth should therefore be taken with caution at this time.

As expected, the performance of each system was impaired by the presence of the others. The WLAN throughput decreased in the presence of both, the

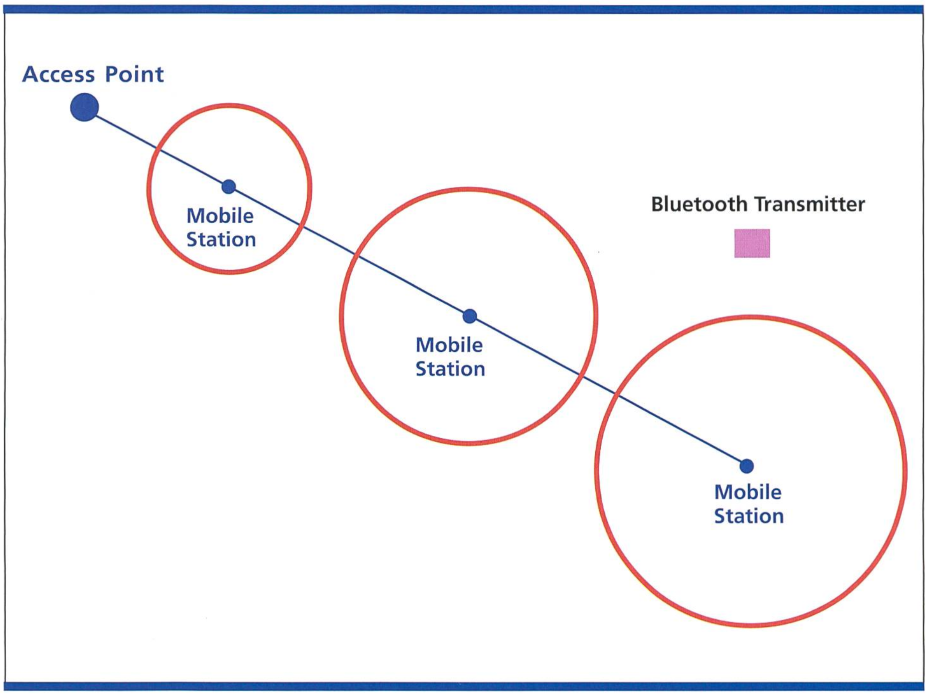

Fig. 6. Forbidden zone circles (not drawn to scale). The circles around the mobile stations represent the forbidden zones where the Bluetooth interferer should not enter if the WLAN link is to work properly.

Abbreviations

DECT	Digital European Cordless Telephony
dB	decibel
eel	Electromagnetic Effects Lab
EMC	Electromagnetic Compatibility
FM	Frequency Modulation
GSM	Global System for Mobile Communication
IEEE	Institute of Electrical and Electronics Engineers
ISM	Industrial Scientific and Medical Equipment
LAN	Local Area Network
PCMCIA	Personal Computer Memory Card International Association
PDA	Personal Digital Assistant
UMTS	Universal Mobile Telecommunications System
S/N	Signal to Noise ratio
VDSL	Very high bit rate Digital Subscriber Line
WLAN	Wireless Local Area Network
www	world wide web

Video Link and Bluetooth. The effect of the WLAN on the Video Link was to cause frames and sound to be received incorrectly. Perhaps the most striking effect is that of the Bluetooth PCMCIA prototypes on the WLAN. In fact, the latter stops working (0 throughput) in the presence of the former.
Using the cable bound technique described above, it was possible to determine that our 11 Mbit/s WLAN operates properly when S/N, the ratio of the wanted signal power to the unwanted signal power (noise), is greater than 6 dB.
Utilising simple formulas that relate the power transmitted by an antenna to the received power near another antenna, and using the standardised parameters of the WLAN and Bluetooth systems, it is possible to estimate the minimum distance that a Bluetooth device can be placed from a WLAN receiver before interference occurs. In what follows, we will give the results without derivation. To avoid interference, it turns out that the distance from the Bluetooth interfering transmitter to the victim mobile station should be greater than one tenth of the distance between the WLAN mobile station and the access point. If we assume that a WLAN access point is 3 to 30 metres away from a laptop then the Bluetooth devices should be at least 0,3 to 3 metres away from the laptop for the WLAN link to perform correctly.
The access point in figure 6 serves three mobile stations that are at different distances from it. The circles represent forbidden zones where the Bluetooth transmitter should not enter if the WLAN is to function properly. The closer the mobile station is to the access point, the smaller the forbidden circle (that means the disturbing Bluetooth sender can get closer to the mobile station without interfering with the WLAN's performance). The reason for this is simply that the mobile station closest to the access point receives a greater signal level from the device accessing the WLAN. A greater noise level is therefore needed to disturb that mobile station.
The above analysis assumes that the WLAN operates in an open space without walls. If walls are present, the WLAN signal from the access point will be attenuated and the forbidden zone circles will grow.
Since Bluetooth is meant to be installed in every electronic device and appliance, the problems described here are of considerable importance. The IEEE 802.15 committee has realised this and has recently set up a working group to look into these problems in order to propose solutions. Corporate Technology is currently participating in that working group.

Guidelines and Countermeasures

There are a number of approaches being evaluated to solve the Bluetooth/WLAN coexistence problem described above. These are:
1. Installation guidelines for the WLAN access points based on the acceptable radii of the forbidden zone circles.
2. Utilisation of smart antennas that send and receive in selective directions that adapt automatically to the position of the corresponding station.
3. Use of minimum necessary power to minimise interference to other stations (power control).
4. Introduction of frequency planning in the ISM band.
5. Use of shielding measures.

Conclusions

A key to the success of the new technology-driven economy lies in the fulfilment of a scenario where ubiquitous, wearable computers will wirelessly, spontaneously and seamlessly connect to each other and to the www. This will allow Swisscom to offer a broad range of services to its customers. This scenario requires that transceivers, be it WLAN, Bluetooth or others, work reliably and with a sufficiently high quality of service to gain the trust of the potential customers. This requirement cannot be realised unless proper EMC is ensured.
Two of the most important emerging wireless technologies are Bluetooth and WLAN. The interference between these

Zusammenfassung

Prozessoren werden immer schneller, kleiner und billiger. Dies ermöglicht eine Art Revolution: Kleine Sender werden überall anzutreffen sein, in Laptops, PDAs, Haushaltsgeräten, ja sogar in unseren Kleidern. Alle diese Sender werden sich um die beschränkten Frequenzen streiten, was zu Interferenzsituationen führt. Dies wird der Zuverlässigkeit und der Qualität der Dienstleistungen schaden. Wir haben zwei wichtige kabellose Systeme untersucht: Bluetooth und WLAN. In Gegenwart von Bluetooth Sendern haben wir eine markante Beeinträchtigung der WLAN Funktionen beobachtet. Zurzeit wird an Installationsrichtlinien und Gegenmassnahmen gearbeitet.

two systems has been identified and characterised. Guidelines and countermeasures are being developed to ensure good quality of service and reliability.

Outlook

The acceptable level of interference in a wireless system is a function of the particular service that the system will carry. While a few bit errors may be acceptable for voice communication, the requirements for data are higher. Latency created by retransmission of erroneous packets, on the other hand, may be a problem for streaming video or audio services, but it is less of a problem when surfing the Internet. Work is being planned to adapt EMC countermeasures to the types of services in order to generate savings by right-sizing countermeasures and to provide superior quality of service and reliability for the services that require it. 8

Acknowledgment

The author wishes to acknowledge the work of the "1 GHz" project team, on which this article is entirely based. The team members are, in alphabetical order: Monira Abu El-Ata, Enrico Blondel, Peter Fritschi, Jingming Li Salina, Claude Monney, Beat Mühlemann, Bàlint Szentkuti and Erich Zimmermann.

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FORSCHUNG UND ENTWICKLUNG

Video über das Handy

Die japanische NTT DoCoMo will bis Ende 2000 einen Videoservice über das in Japan stark verbreitete mobile PHS-System vorbereiten. Die Datenübertragung soll mit 64 kbit/s laufen, was wohl nur wegen des kleinen Bildschirms zu erträglicher Bildwiedergabe führt. Über Kosten wurde bisher nichts veröffentlicht. Aber man hat bereits weitergehende Ambitionen: Als nächstes soll die Liveübertragung von Videoaufnahmen aus der eigenen Videokamera vorbereitet werden.

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Internet-Telefonie – der nächste Boom

Kaum ein Geschäft kann derzeit mit so hohen Zuwachsraten auf der Welt rechnen wie die Internettelefonie mit dem «Voice over Internet Protocol» (VoIP). Einem kürzlich in der Zeitschrift «Spectrum» des Institute of Electrical and Electronics Engineers (IEEE) erschienenen Beitrag kann man entnehmen, dass hier die Wachstumsraten bei mehr als 100% pro Jahr liegen (Bild). «World Access» hat gemeinsam mit den japanischen Universitäten Tokyo und Kyoto einen Adapter entwickelt, der VoIP auf Kabel-TV-Netzen möglich macht. Ein Telefonverzeichnis der Netzteilnehmer ist gleich eingebaut. Der Adapter soll für weniger als 100 US-$ gefertigt werden.

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Japanisches Postministerium erwägt jetzt Stratosphärenkommunikation

Einem Bericht der «Nikkan Kogyo» zufolge will das japanische Post- und Telekommunikationsministerium eine «Stratosphere Wireless Platform Initiative» ins Leben rufen, welche die Nutzung der Frequenzbänder bei 28 GHz und 31 GHz vorbereiten soll. Wie bereits früher berichtet, will man unbemannte Luftschiffe in die Stratosphäre entsenden, die entsprechende Geräte für drahtlose Kommunikation an Bord haben. Auf der jüngsten Konferenz des World Radio Council in der Türkei wurden zwölf asiatischen Ländern entsprechende Frequenzen zugewiesen. Die Frequenzbereiche um 30 GHz haben gegenüber dem bisher diskutierten Bereich bei 47 GHz einen entscheidenden Vorteil: Sie sind weniger Störungen durch Regen ausgesetzt.

MIT-Roboter trainiert Schlaganfallpatienten

Nach einem Schlaganfall kommt es häufig zu Sprach- und Gedächtnisproblemen, aber auch zu einer Einschränkung der Bewegungsfähigkeit. Durch intensives Training können diese Behinderungen weitgehend wieder beseitigt werden. Am Massachusetts Institute of Technology (MIT) hilft nun ein Roboter bei der Wiederherstellung der Beweglichkeit. Er ist gegenwärtig auf das Training der Armbeweglichkeit ausgelegt, aber andere Roboter werden sich auch mit den Beinen und den Handgelenken beschäftigen. In die laufenden Tests sind 56 Patienten involviert: Mit signifikantem medizinischem Erfolg, wie von Professor Neville Hogan berichtet wird.

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