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The communication channel in urban operations - A first survey

Abstract (not more than 200 words)

Military operations in urban environment are in general conducted with dismounted solders, both outside and inside buildings, including below ground in basements and culverts. Situation awareness is essential, position and status of team members are very important information for every solder.
Communications is therefore essential for command and control, and wireless is the only means where radio is the prime technology.
Free space optics (FSO) may be an alternative to radio communication in urban areas, due to less jamming and interception sensitivity, high bit rate and no licensing or frequency allocation needed. However, the atmospheric effects, i.e., turbulence and attenuation, limit the availability of free space optics links.
Even the radio channel sets limits for present and future wireless communication system. A thorough understanding of wave propagation is important and when calculating the wave propagation a number of propagation mechanisms need to be accounted for, i.e., transmission loss, arrival times, phases, delay spread and correlation bandwidth.

Keywords

Wave propagation, urban environment, radio, laser, modelling

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Sammanfattning (högst 200 ord)

Militära operationer i urban miljö innebär att soldater, oftast till fots, rör sig utomhus, inne i byggnader och under marknivå i kulvertar. Lägesuppfattning är av stor betydelse och position och status på gruppmedlemmarna är viktig information för varje enskild soldat. Kommunikation är därför av stor betydelse för spaning och ledning och trådlös överföring är en viktig komponent med radio som främsta medel.

Fri optisk kommunikation (FSO) kan vara ett alternativ till radiokommunikation i urban miljö tack vare störtåligheten, smygegenskaper, hög bithastighet samt att vare sig licens eller frekvensallokering behövs. Dock skall man vara medveten om att atmosfärseffekter, turbulens och dämpning, begränsar användandet av fria optiska länkar.

Även radiokanalen sätter begränsningar för dagens och framtida trådlösa kommunikationssystem. En grundläggande förståelse för vågutbredning är viktig. När man beräknar vågutbredningen måste man ta hänsyn till flera mekanismer, typ transmissionsförlust, tidsfördröjning, fas, spridning och korrelationsbandbredd.

Nyckelord

vågutbredning, urban miljö, radio, laser, modellering

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Table of contents

1 Introduction

In January 2003 a new project called "*The properties of the communication channel in urban environment*" (in Swedish: Kommunikationskanalens egenskaper i tätort – KOMET) was started at FOI Command and Control Systems in Linköping. The project will focus on the physical limitations of the radio channel and develop wave propagation models for typical military scenarios in urban environments. The project will also study the possibility to use free space optics (FSO) as an alternative to radio communication.

With this report we summarise our initial studies over probable scenarios in future military operations in urban environments and give a few examples of radio systems of interest for such applications. We also give a brief introduction to laser beam propagation and atmospheric effects on free optical communication. In chapter 4 we discuss radio wave propagation modelling in general and in chapter 5 we give a few examples of software for modelling urban propagation. Finally we conclude our report by a discussion leading to a suggestion for the next step in our studies.

2 Scenarios

In the future, the armed forces must be able to quickly respond to different types of threats and risks. The Swedish parliament has therefore decided that the armed forces are to be developed to the concept of network-based defence [1].

A network-based defence will, among other things, provide enhanced battlespace awareness to the military forces. The requirement of a common picture of the battlespace will lead to an increasing data flow in the communication network. Interoperability with the vital functions of the civilian society and with partners in international peace support operations is essential. Therefore there is an increasing need of flexible and high capacity wireless links as components in the network.

Operations in urbanized environment will be a more common task for the armed forces, both within Sweden when supporting the society in times of severe peacetime difficulties and abroad in international peace support operations. In many ways the communication scenarios may differ from those of peacetime civilian telecom, e.g. with respect to frequencies and waveforms used, locations of terminal antennas, possible base station infrastructure and interference and jamming environment. As a consequence, there is an increasing need for understanding and modelling the radio wave propagation in urban terrain with particular focus on the military scenarios.

2.1 Military operations in urban environment

Military operations in urban environment are in general conducted with dismounted soldiers, both outside and inside buildings, including below ground in basements and culverts. Different types of vehicles can be situated in narrow streets where walls and houses are blocking the line of sight between them. Rapid information from the civilian authorities e.g. drawings of buildings, structures and streets are advantageous. Status information of buildings is desirable. Take a factory as an example: where is the fuel deposit, storage of explosives and other chemicals, where are the culverts between buildings and so on. Situation awareness is essential; position and status of team members are very important information for every soldier.

A Swedish mechanized combat squad today [2][3] has typically one heavy tank (strv 122), one combat vehicle (strf 90) and thirteen soldiers, five to six of them can be dismounted. A platoon is composed of 1 – 3 combat squads, a commander and his deputy. The vehicles in the mechanized combat squad have great firepower capable of penetrating any normal building but the squad is vulnerable against smaller targets like snipers armed with antitank weapons. Obstacles in the form of walls and buildings are often near, 10 – 100 m and 30 m high or more. This means that assaults from above and behind or from the side is a great danger for the team. To prevent this, the dismounted soldiers have a main task to protect the vehicles by scanning the nearby surroundings, to detect and, in many cases, defeat enemies around corners, on rooftops and in windows.

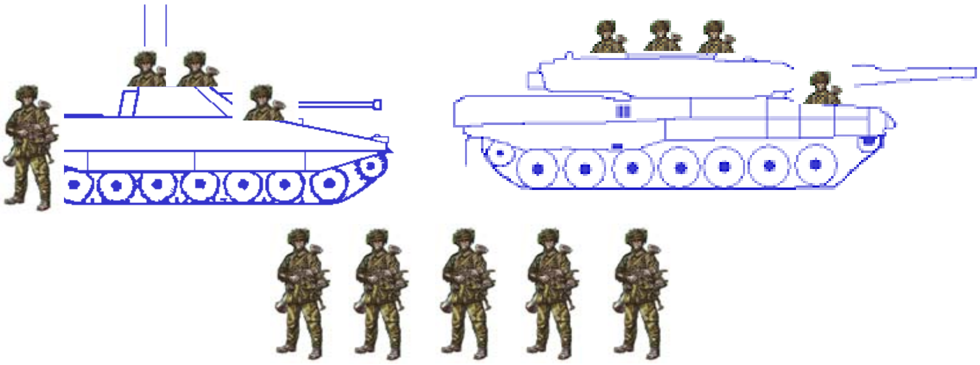

Figure 2.1: Mechanized combat squad.

The Swedish mechanized battalion is mainly equipped for combat in relatively open terrain, and has too few soldiers on foot for urban environments. To penetrate buildings and search them, there is a need for more soldiers. A proposal from the Army Combat School [4] is to put one group of 10 – 12 soldiers together with every mechanized combat squad. When fully deployed is this half-company then around 80 soldiers, 3 heavy tanks, 3 combat vehicles and 4 troop transport vehicles. This force can secure an area of 300 x 300 m or patrol an area of 2 x 2 km in urban environment.

Communication is essential for command and control. Wireless is the only means and radio is the prime technology. Communication within the platoon inside and through buildings up to a distance of 2 km is common, sometimes even below ground level into basements or similar. Communication outside the platoon is common up to a distance of 10 km. In the proposal from the Army Combat School every soldier is equipped with an intra-team personal radio for communication within their own group.

Radio communication systems in the future are capable of using frequencies from 2 to 3000 MHz or more [5]. Available frequencies for military use are mainly in the 2 – 30 MHz, 30 – 90 MHz, 225 – 400 MHz and 1350 – 1400 MHz bands. Frequencies below 100 MHz are not well suited for personal units because of the relatively large physical size of frequency dependent components, especially the antenna. High frequencies, on the other hand, do not propagate well through walls and other obstacles, which would increase the need of relay stations to get sufficient coverage. A trade-off between these demands is to use frequencies in the range of 100 to 500 MHz. Frequencies between 500 and 2500 MHz can also be used but this would stress the need for relay stations to cover the operation area in an urban environment.

It is not very likely that a small pocket sized radio can monitor more than two networks in the near future. The vehicles, on the other hand, can be equipped with more sophisticated radios capable of monitoring several networks, will have better antennas and more transmit power and can serve as relays for the personal units.

Today, the Swedish mechanized battalion is mainly equipped for combat with vehicles in relatively open terrain and this implies that the radio communication systems also are designed for such scenarios. Military operations in urban environments clearly put different demands on the communication systems than traditional terrain does; urban environment is difficult from the wave propagation point of view.

The lack of line-of-sight propagation forces the radio waves to diffract over rooftops and around corners. Furthermore, the waves will reflect against and scatter at, not only big obstacles, like walls and asphalt, but also cars parked in the street, lamp posts and traffic signs. The amount of reflections and scattering depends on the frequency, angle of arrival and the surface material. This results in multipath propagation and high attenuation, which involve disturbances and interruptions in the transmission.

For situations where soldiers act indoors the radio waves have to penetrate walls and floors of different material. The penetration is strongly frequency dependent. Transmission of a high frequency signal through a dense, thick wall or floor may cause interruptions, due to the high attenuation. Similar problems occur if soldiers move in a subway or a culvert. The radio wave may not reach the environment outside unless one or several relay stations are used.

2.2 Examples of radio equipment

2.2.1 Short Range Radio

The Short Range Radio (SRR) is developed by SAAB AB [6] in cooperation with FMV, the Swedish Defence Materiel Administration [7], for the Gripen project. SRR allows full-duplex, voice-controlled conference calls in noisy environments where the users need hands to be free for purposes other than pushing buttons. The Swedish Air Force uses the radio in its preparations for the Gripen fighter. The SRR, which is in its third generation, is also being evaluated in several countries for other services in future military systems.

The radio system operates on the 2.4 GHz frequency band with 50 user selectable channels. All transceivers set to the same channel form a conferencing group with up to 30 members. Within these groups both voice and data can be communicated and five members in a group can speak simultaneously. A priority function allows any user to speak at any time for emergency voice messages. External systems, e.g. the intercom system of a vehicle or a long-range radio system, can be connected to an access point transceiver for participation in the SRR network.

The SRR system uses a transmitter output power between 1 mW and 100 mW and has a dynamical function to automatically adapt the power to the current situation. At full transmit power the line-of-sight range is around 800 m. Inside buildings the range is much shorter due to the blocking of the radio signal by the walls.

Figure 2.2: SAAB SRR300 portable transceiver. Source: [6].

Figure 2.3: SAAB SRR360 access point transceiver. Source: [6].

The intended users of the system, e.g. the support crew around military aircrafts, have a very noisy environment and therefore the SRR is equipped with a reference microphone and an active noise reduction function. In addition to that, the SRR has the ability to digitally relocate different sources to fixed audio directions. This means that the user will hear, for instance the commander at sight, always from a fixed direction and in that way the speech intelligibility will be enhanced. The direction from which an audio source appears is a configurable parameter in the radio.

2.2.2 Terrestrial Trunked Radio

In Sweden there exist many different legacy systems for public safety communications. Different organizations have different systems and are unable to communicate with each other. The government has appointed a committee, to investigate how a joint communication system for public safety can be realized [8][9]. One candidate for such system is a system based on the TETRA-standard.

Terrestrial Trunked Radio (TETRA) is a standard by ETSI [10] for public safety communication. TETRA is a cell based system for both voice and data in the 380 – 400 MHz band, with many additional features specifically designed for public safety operations, compared with commercial systems like GSM. A few of the additional features are: end-to-end encryption, group calls, priority and direct mode calls. Every TETRA terminal can operate in four different modes depending on the situation.

1. In trunked mode operation, TMO, the terminal acts like an ordinary cell-phone with the additionally ability to form groups and make group calls. Calls in a TMO network are always routed through a base-station. Access to the public switched telephone network (PSTN) and packed data network (PDN) are possible through gateways in the base-stations.

2. In direct mode operation, DMO, calls are set up directly from one mobile station to another mobile station or to a group of mobile stations without any assistance from the base-station. A network of mobile terminals in DMO can be totally independent of any infrastructure.
3. When a terminal is in dual-watch mode, DW, it is a member of one TMO network and one DMO network. The DW terminal acts as a bridge to and from the DMO network and in that way extending the cell coverage of the TMO network.
4. The fourth mode is the repeater mode. For instance, when a user goes inside a building with bad radio coverage, a vehicle outside with better antennas and more transmit power can be designated as a repeater for that user.

The drawback with TETRA is that the standard, today, contains many optional functions from which the manufacturers can choose. Two terminals from different manufactures may be able to interact with each other, but there is no guarantee for this. The air interface between the base-station and the terminal is well defined, but the interfaces between sub-systems in the infrastructure are not that well defined, as they are in GSM for instance. This means that it can be difficult to mix sub-systems from different manufactures. As the market grows for TETRA-systems we anticipate that these problems will fade away.

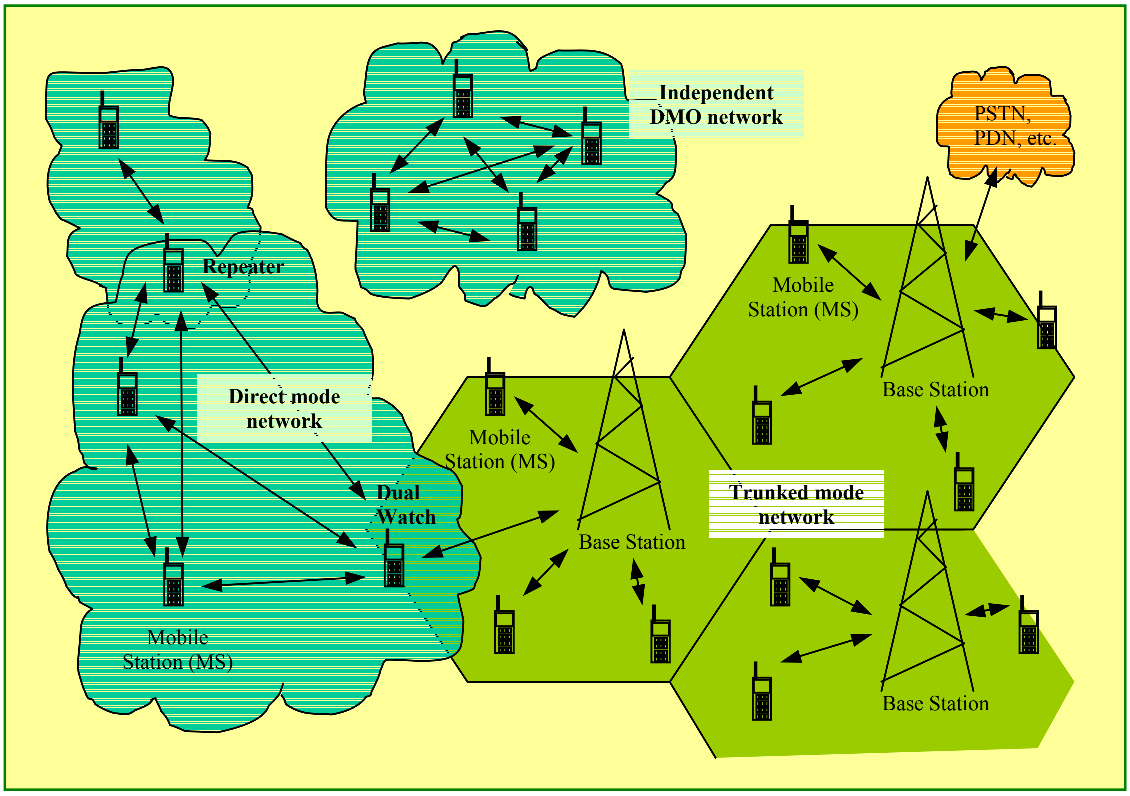

Figure 2.4: The TETRA system

2.2.3 Small Unit Operations – Situation Awareness System

Defense Advanced Research Projects Agency [12], DARPA, started the Small Unit Operations – Situation Awareness System (SUO – SAS) project in 1997 with six months of trade studies followed by a 12 months of risk reduction and technology research phase carried out by ITT and Raytheon. In 1999 DARPA appointed ITT as the prime contractor for development of a prototype system.

The SOU – SAS system is a combined inter/intra communication system and a situation awareness processing and display system for soldiers on foot, sometimes aided with vehicles. The system provides robust, reliable and secure communication (LPI, LPD, LPE and AJ) with self-organizing network management (ad hoc). Position, navigation and other sensors are integrated to provide situation awareness presented to every soldier. The communication is able to operate in difficult signal environment, such as in "urban canyons", inside buildings, tunnels and caves with their typical multipath problems as well in forests. DARPA has spent around $100 million on the six-year project.

The key component in the SUO – SAS system is the radio that operates in the frequency range of 20 – 2500 MHz. The operator selects a frequency pool or frequency sub-bands, which the radio then uses. The radio uses direct sequence spread spectrum combined with frequency hopping to overcome multipath fading and jamming. The data rates are adaptive between 16 bps up to 4 Mbps. The carrier and data rate spectrum lines are suppressed (40 dB) by applying a random phase in order to protect the signal from signal intelligence with feature detectors. Information is delivered in packets and the radio adapts the carrier frequency, data rate, coding rate and output power on a packet-by-packet basis. According to DARPA, the SUO – SAS system is built to the JTRS architecture, the only architecture supported by the DoD.

The ad hoc network is formed into clusters, with up to 50 members in every cluster. The system automatically appoints nodes for bridging over to other clusters. The maximum size of the network is 50 clusters. The ad hoc algorithm consumes on average 7 % of the total capacity of the network.

Position and navigation aid are based on GPS and measurements of message time-of-arrival. One node can determine its relative position with an accuracy of 1 m including height relative all other neighbours independently of GPS. This is necessary inside buildings where the GPS reception is bad. The positions are then distributed to provide a situation awareness bubble around the user.

The SUO – SAS radio can operate in six different modes, each optimised for; clandestine, long range, jam resistance, ranging accuracy, high data rate and interoperability with SINCGARS[1]. All functions are not available in all modes and all modes are not implemented in the prototypes (dec 2002).

A simulated rescue of a downed helicopter crew was performed in October 2002 with the SUO – SAS system [11]. The demonstration was held at the McKenna Military Operations in Urban Terrain Training Center at Fort Benning, Georgia, USA, and was designed to replicate the type of urban rescue situation that occurred in Mogadishu, Somalia, in 1993. During the

[1] SINgle Channel Ground and Airborne Radio System, US armed forces combat net radio.

company-level operation, approximately 50 airborne, mounted and dismounted soldiers used SUO – SAS equipment to maintain a common situational awareness picture and reliable, secure communications as they manoeuvred through heavy forests and open areas and then entered a building within a mock city to rescue the downed aircrew. Soldiers had constant access to voice, data, and geographic position information. SUO – SAS used non-GPS techniques to provide the troops with precise geolocation information even inside buildings where GPS does not work. As the rescuers came closer to the downed aircrew, the aircrew's SUO – SAS radio automatically joined the rescue team's network. The geolocation information allowed soldiers to identify not only the building, but also the room and floor where the downed pilots were hiding.

According to DARPA [12], the field demonstration got a "big thumb up" and the DARPA founding officially ran out at the end of 2002. Jane's Defence Weekly [11] reports that there is no recognized plan to hand off the program to any of the services. The next step would be to miniaturize the prototype; the goal is a 1.5 kg single box including batteries for 72 hours of operations. The prototype of today is a three-box solution, computer and radio in one box, batteries in a second box and geolocation system in a third box. All three are mounted on a backpack frame.

Figure 2.5: ITT SUO - SAS prototype. The flat box on the left is the radio and computer with three antennas on top. The bulky box on the right is the battery box and the box below is the geo-location system with its flat circular antenna above the battery box. Source: [13].

Figure 2.6: Early ITT design goal for the SUO – SAS system. All the components in a 1.5 kg box, including battery, but its realization falls outside DARPA's project. Source: [13].

3 Laser beam propagation

3.1 General

Free space optics (FSO) could be a complement to radio communication in urban areas, due to less jamming and interception sensitivity, high bit rate (up to a few Gbps) and no licensing or frequency allocation. The availability of FSO line-of-sight links is limited by the atmospheric effects, i.e. turbulence and attenuation. Communication in urban areas also implies other perspectives. First, the communicating units may be in movement and second, there may be obstacles preventing free line-of-sight between the units. The research today is not mainly about atmospheric effects, but most about how to communicate between moving platforms, using beam steering and retro-reflectors for the alignment.

3.2 Laser beam propagation in the atmosphere

Turbulence effects in the laser beam appear as a result when warm and cold air pockets (turbulence cells, called optical turbules) meet, which especially happens close to ground when the sun shines. Fluctuations in the index of refraction resulting from small temperature fluctuations cause distortion of the wavefront [14]. If the turbulence cells are smaller than the beam diameter scintillations will occur (se figure 3.1). This is a result of constructive and destructive interference as the beam propagation length varies. If the turbulence cells are larger than the beam cross section diameter beam wandering occurs, i.e. the whole beam bends. The amount of power fluctuations from turbulence is larger with small receiver apertures and close to ground, walls and rooftops.

Fog and precipitation cause attenuation of the laser beam. Snow and rain result in less attenuation than fog. Thick fog makes free space optical communication difficult due to the large attenuation and the limited power of the lasers.

The wavelength bands suitable for FSO are the wavelengths around 780, 850 nm and 1550 nm, due to the lasers available (development pushed by the fibre optics industry) and the good propagation characteristics in the atmosphere of these wavelengths. The attenuation is much the same for these wavelength bands in heavy fog. The fact that wavelengths longer than 1400 nm are eye safe up to higher power levels may be more important in the choice of wavelength than the propagation characteristics.

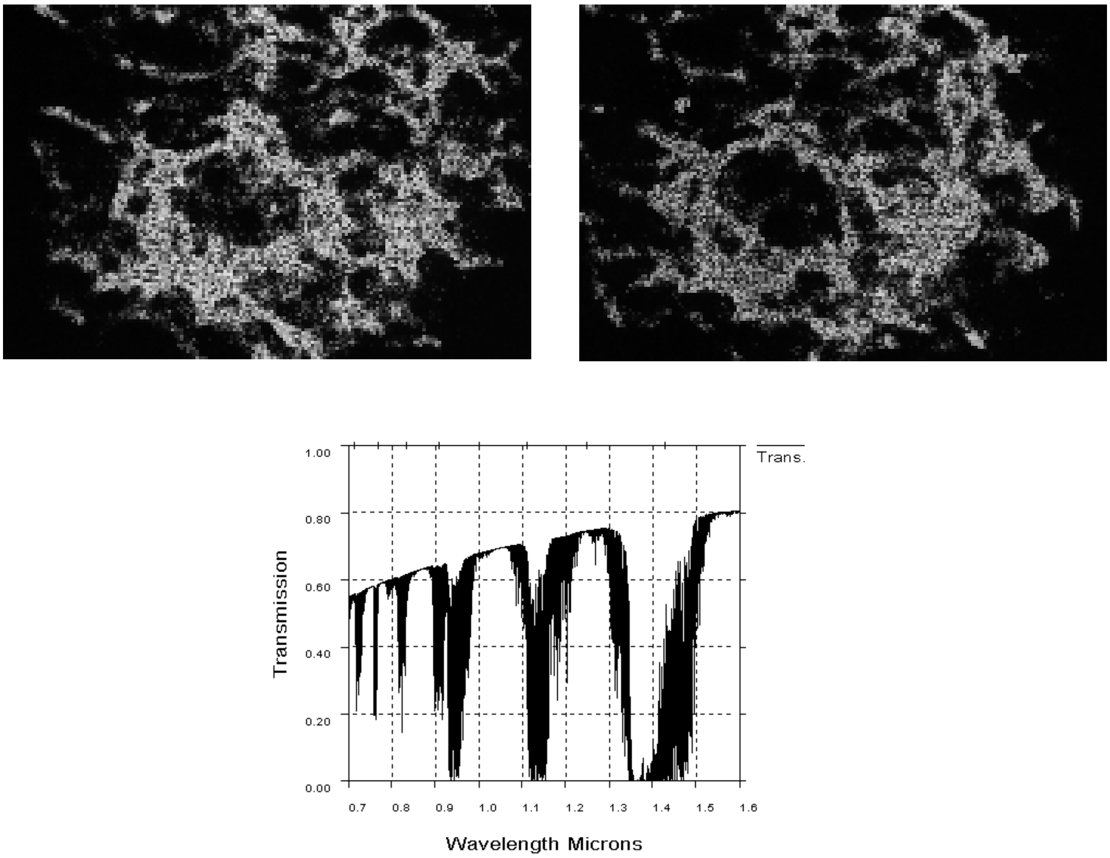

Figure 3.1: Atmospheric effects. The two pictures show scintillation effects in beam cross-section after 1 km propagation of a 515 nm laser beam in weak turbulence (20 ms between pictures). The graph shows wavelength dependence of laser propagation from a simulation in Modtran. The propagation path is 1 km, the visibility is 5 km and the altitude is 2 m.

3.3 Diffuse laser beam reflections

A possibility could be to communicate using diffuse reflections. The relatively low power of the lasers or LEDs results in a limited range from the reflecting surface to the receiver, because of the power losses when the beam diffusively reflects against a surface. Multipath reflections may also affect the signal detection, causing intersymbol interference. The receiver field of view is preferably wide in a system using diffuse reflections. A wide field of view results indoors in a high amount of noise from light sources and outdoors from the sun radiation. Optical bandpass or longpass filters can be used in front of the receiver to reduce noise from other light sources and the sun. A paper about using diffuse reflections in indoor wireless infrared communications has been published by Kahn and Barry [14].

4 Wave propagation modelling

4.1 General

The radio channel sets limits for present and future wireless communication system. This is true regardless of the nature of the propagation environment, be it a rural area or urban or indoor scenarios. A thorough understanding of wave propagation is important for several reasons:

- The properties of the channel are given by the environment of the propagation link
  - This gives possibilities as well as constraints for safe communications
  - Knowledge about these can give operative assets

- New technologies require new knowledge about the channel
  - Channel models are essential in system assessment
  - New concepts can be evaluated in the lab without expensive field trials
  - Wide range of environment parameters can be tested

- Electromagnetic war is fought by means of propagation channels
  - Own and hostile channels are different
  - These can to some extent be affected by the location of the terminals

- Wave propagation aspects affect the choice of important design parameters such as:
  - Carrier frequency
  - Bandwidth
  - Modulation and coding
  - Transmitter power and antennas
  - Geographical location

- These, in turn, determine system performance expressed in terms of:
  - Availability
  - Capacity
  - Message delay
  - Bit error rate
  - Robustness to interference

In general, when calculating the wave propagation a number of propagation mechanisms need to be accounted for:

- Free space propagation
  - Intensity decays as $1/(\text{distance})^2$

- Reflection
  - At large objects compared to wavelength
  - Ground, buildings, walls etc

- Diffraction
  - Obstacles along free-space paths
  - Terrain or buildings
  - Wave bends around the objects

- Scattering
  - By objects small compared to wavelength
  - Terrain roughness, foliage, smaller man-made objects
  - Emission of secondary waves in all directions

- Attenuation along ray path
  - Penetration through semi-transparent obstacles
  - Vegetation
  - Building walls (wood, glass, concrete etc.)
  - Precipitation and dust
  - Energy is lost from the wave to the medium

Large objects in the environment can cause shadowing of the line-of-sight path. The major signal contributions may then arrive at a receiver from many directions simultaneously, so-called multipath. This causes delay spread and, in the case of moving terminals, signal fading and doppler spread and shift and may degrade system performance. On the other hand, with antenna arrays in MIMO systems (multiple input, multiple output) the multipath situation is turned into an advantage to increase the system capacity.

4.2 Characteristics of channel models

In the past, wave propagation calculations seldom provided any channel information beyond the transmission loss. However, this may be sufficient for narrowband systems where the entire transmission passband shows the same characteristics. The transmission loss can be obtained from 2D deterministic wave propagation models such as those implemented in DETVAG-90 [16]. The other important type of models in this class is the empirical models based on channel measurements in representative environments, possibly together with some theoretical considerations; see e.g. the Okumura-Hata model or the COST 231-Walfisch-Ikegami model [17],[18]. In all these, the different received signal contributions are added together without consideration of phase.

For broadband systems the multipath components are added with their arrival times and phases. Besides transmission loss the channel is also characterized by its delay spread and correlation bandwidth. Depending on the situation the full channel can be described by one of two formally equivalent representations, viz. the impulse response or the transfer function.

When mobility is a part of the scenario dynamical propagation effects may become important. They impose fading and doppler spread and shift on the signals. In such cases the exhaustive channel description is given by the time-variant impulse response or transfer function.

A further dimension in the channel modelling arises with the use of smart antennas and in MIMO applications. For these the multipath components are needed together with spatial information, i.e. the directions of departure and arrival of the various signal components.

These kinds of models are denoted directional – or even double-directional – channel models. A MIMO channel with M_T and M_R antenna elements, respectively, is

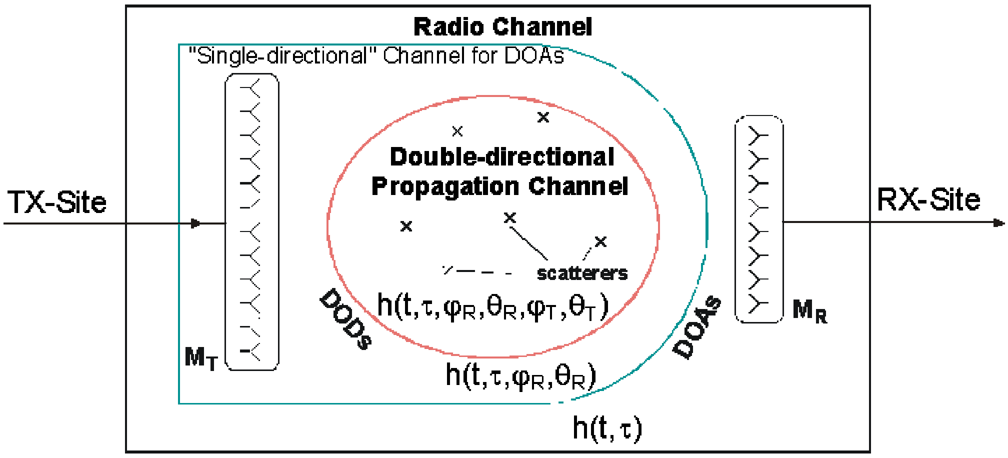

Figure 4.1: Structure of a double-directional channel model; from [19]. The outermost layer indicates the channel described in the signal dimension, i.e. by the signal or antenna currents in the sub-channels on the two sides. The propagation environment is described by the positions and strengths of the individual scatterers indicated within the red boundary. These, together with the information about the antenna arrays, determine the parameters of the double-directional channel model.

described by an impulse response matrix with $M_T \times M_R$ elements. A recent review of such models has been published by Molisch [18]; see also a paper by Steinbauer et al., [19] and fig. 4.1. Channel models for studies of future wireless systems will probably be of this most general kind and therefore we will focus on such models in the forthcoming.

Besides the general aspects described above, channel models are sorted into two broad classes of models suitable for somewhat different applications, viz. stochastic and deterministic models. The meaning of those concepts is discussed somewhat further in the following two subsections.

4.2.1 Stochastic models

In system simulations one is often interested in the performance of a system for a broader class of propagation environments rather than its behaviour in a precise geographical location.

Stochastic channel models are well suited for such simulations and several models have been developed based on extensive measurements. The implementations are in general fairly straightforward and result in computationally rapid codes. The models can be used in a standardized way for comparison of results between different laboratories.

A purely stochastic channel model does not contain any wave propagation; instead statistical distributions for signal properties directly simulate all aspects of the impulse responses. For each simulation realizations are drawn from the ensembles representing those signal properties for the specified environment. The COST 207 model is an early example of such models. More recently this has been extended to provide directional information; see [18].

Geometry-based stochastic models mix the properties of stochastic and deterministic models. The impulse response is here related to the presence of scatterers whose locations in the propagation geometry and strengths follow probability distributions dependent on environment. The impulse response is generated by simple ray tracing formulas, assuming single scattering via the realization of scatterers for the actual case. From the way the model is constructed complete information regarding delays, phases and directions of departure and arrival is inherent from the beginning. The dynamical properties of the channel for movements over moderate distances are obtained by a simple temporal extrapolation of the impulse responses.
The most up-to-date model of this kind is the COST 259 directional channel model [21],[18]; see fig. 4.2. At present there is no publicly available software with this model.

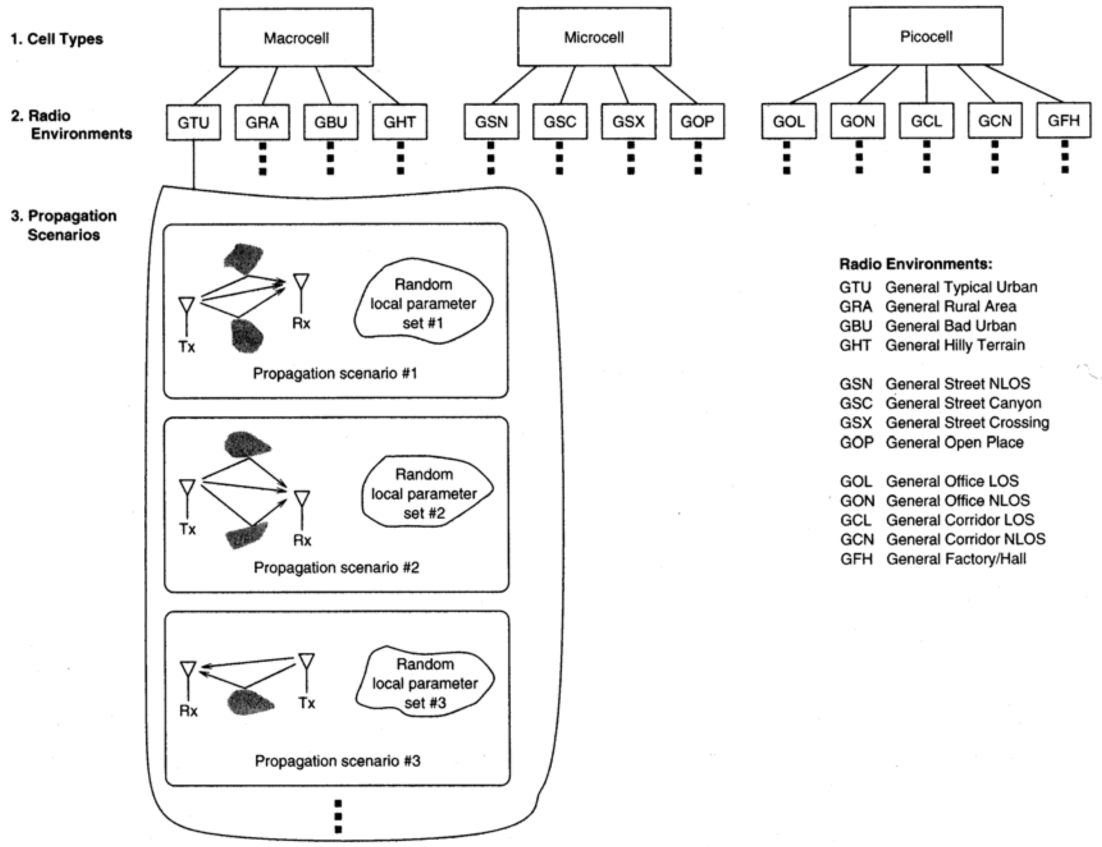

Figure 4.2: Radio environments defined in the COST 259 directional channel model [21].

4.2.2 Deterministic models

Site-specific information about the propagation channel will often be of essence to get adequate predictions about the performance of communication systems in military scenarios under study. The most accurate channel models are probably obtained from actual channel measurements in the terrain. Methods to derive the necessary information from such sounding data, including perhaps also the multipath structure of the received signals, are reviewed in [18].

However, channel soundings are expensive and time-consuming. It is very seldom practicable to measure all potential locations of deployment for a communications link. When focus is on the site-specific channel properties one therefore in most cases has to resort to deterministic wave propagation calculations.

Deterministic calculations rely on a database with geographical and morphological information. For detailed computations in urban areas a database with building plans with much better than metre precision (depending on frequency) must be available. The most popular deterministic wave propagation models today are based on physical optics or the geometrical theory of diffraction (GTD); see Chapter 2 of [22]. These models can account for all propagation effects listed in section 4.1 above. Models based on parabolic equation technique (PE) are under development, but available codes are mainly restricted to 2D propagation; Section 3.3 of [17].

Over the last few years a wide-band double-directional channel model and software has been developed in collaboration between FOI and AerotechTelub under a contract from FMV. The various parts of this have been published extensively in internal memos; see e.g. [23]–[26]. The model is mainly based on deterministic calculations for rural terrain, but includes a stochastic branch that also covers urban environments.

5 Softwares for modelling of urban propagation

There is today an abundance of wave propagation calculation tools for planning of mobile wireless networks. A more or less updated list of available products can be found on the site http://www.members.shaw.ca/propagation/planning.html

Within the above-mentioned collaboration between FOI and AerotechTelub a few commercial softwares for computations of urban propagation have been considered [27]–[29]. Some conclusions from this work are cited below.

All products dealt with here perform deterministic wave propagation calculations for urban scenarios described by a building database. Different softwares require somewhat different formats for these data. However, in all programs some kind of vector format is needed. Building databases have been produced by Lantmäteriet for the major Swedish cities. However, adapting these data to various softwares has been a far from trivial task. Although there are several standardized building data formats, e.g. DXF, Shape or ESRI Generate format, there seem to coexist various not fully compatible dialects of these among different producers. Adaptation of Swedish data has been attempted for three of the softwares and has implied data conversions that were successful only after consultations with the program manufacturers [29]. Price levels are indicated for some of the programs. These pertain to 2001.

5.1 WinProp

WinProp is a software we just recently looked at. It is produced by AWE Communications, Gärtringen, Germany [17]. The manufacturer states a price for a one-year licence for an urban plus indoor module EUR 16 800; twice that price for an unlimited license.

We have made a small investigation into the evaluation software that is free to download at the web address [17]. WinProp consists of three software tools:

- ProMan, which performs network planning and wave propagation calculations
- WallMan, which generates building databases
- Aman, which produces and modifies antenna patterns

We have looked at the tools ProMan and WallMan and the indoor and urban scenarios. It is not possible to use a file generated in one of the tools in a different one using only the evaluation software, however, this is possible with the full licence.

It took some effort to get ProMan started. The users manual is useful for finding specific information but is not so helpful when you start the software the first time. The information needed is spread over different places in the document. However, once the initial phase is passed, the use of the software is quite straightforward.

With the experience gained with ProMan it was much easier to get started with WallMan, since the software tools are organized in a similar way. The software supports dxf files as input. Since the dxf format is not fully standardised this might cause trouble when importing files from other softwares. The dxf file we used for the test generated a lot of error messages but it seems to be functional; see fig. 5.1. The height information in the source files was somehow lost, though. It is possible to look at the imported files in booth 2D and 3D view but the database has to be restarted to see the 2D view.

Below, we list the various prediction models in WinProp. We have not tested any of these.

Rural Scenarios

- Okumura-Hata
- Replacement Obstacles
- Parabolic Equations

Urban Scenarios

Requires 3D vector-oriented data of the buildings and can use topological databases for the urban area, if desired.

Deterministic: Ray optical (Ray tracing and ray launching)

- Intelligent Rigorous 3D
- Rigorous 3D (Standard)
- 2D vertical and horizontal plane

Empirical models

- COST 231 (Walfisch-Ikegami model)
- Diffraction model (extended knife-edge-model)

Indoor scenarios

Requires 3d vector-oriented data of the walls of the buildings and their material

Deterministic: Dominant Paths

- Rigorous 3D

Deterministic: Ray optical (Ray tracing and ray launching)

- Intelligent Rigorous 3D
- Rigorous 3D (Standard)

Empirical models

- COST 231 (multi wall model)
- Motley-Keenan

Figure 5.1: Building database over parts of central Stockholm as illustrated by WallMan.

For vegetation objects:

As an alternative to material parameters, two macroscopic parameters can be defined for vegetation objects: The first one, "Additional attenuation of pixels", refers to the prediction inside vegetation. This parameter defines, how many dB the signal is predicted lower due to the presence of vegetation. The second parameter, "Additional attenuation if rays", defines the attenuation of strong rays passing beyond the vegetation.

5.2 RPS

Information on RPS (Radiowave Propagation Somilator) from Radioplan Gmbh, Dresden, Germany [30].

The software is ray based and developed mainly for outdoor and indoor propagation in micro and pico cells. The frequency range given is 0.3—300 GHz, with slow degradation of performance below 300 MHz. Besides two deterministic models two empirical models are implemented. Ray launching can be applied in 2.5D or in 3D. Reflection, diffraction and penetration are accounted for. The complex impulse response is calculated and saved. Also dynamical impulse responses can be generated. The angles of departure and arrival are computed. The antenna radiation function can be interpolated from given tables for the vertical and horizontal plane antenna diagrams.

The over all impression is that this software is well adapted for sharing data with and exporting data to own written program modules written in visual C++ or in Matlab.

5.3 WirelessInSite

The program WirelessInSite comes from Remcom, USA [31]. Total price for modules for rural + urban + indoor environment is 12 000 USD.

The software consists of three modules: urban, indoor and finally a rural module with limited functionality. The computations are ray based with reflections from ground (triangular pixels) as well as from building walls and roofs. Diffractions from corners and edges are calculated with GTD.

The frequency range for the modules is stated as 0.1—6 GHz for urban and 0.3—6 GHz for indoor environments. Outside these ranges the program still can give answers but with degrading performance.

5.4 WaveSight

The WaveSight software is developed by WaveCall SA in Lausanne, Switzerland [32]. Price 15 000 EUR? It is not clear what is included for this price.

The program is ray based and of so-called 2.5D type, i.e. propagation over roofs and around vertical corners are computed separately in 2D calculations. Two reflections and two diffractions at vertical corners are considered. Over roof top diffraction can account for up to 15 diffractions. Penetration into buildings can be calculated assuming a constant loss. Typical outputs generated by WaveSight are transmission loss, time of arrival, impulse response and angle of arrival.

5.5 Discussion on softwares

It is difficult to make direct comparisons between different programs without deep study of the available information. The products differ regarding their price, the duration of the license, technical support and availability of source code. Does the GUI include geographic presentation of the area? What calculations can be done and to what extent can results be exported for direct use by other programs, e.g. Matlab? Can the program handle calculations with transitions between different environments in the propagation area? Various techniques to speed-up the computations are implemented, but these cannot be assessed without running the programs for the same scenarios. In addition, some of the considered programs are being further developed while others may be stagnating.

It is not obvious which of all the capabilities listed for the various softwares are essential for an intended application. If the need arises to use a software of this kind a careful specification of the essential requirements should be written. Only after that a renewed contact with the manufacturers should be taken to enquire the current status of their product.

6 Conclusions and further work

Military operations in urban environment are in general conducted with dismounted soldiers, both outside and inside buildings, including below ground in basements and culverts. Situation awareness is essential; position and status of team members are very important information for every soldier. Having a reliable communication system is important. We have mentioned three radio systems with different capacities and to be able to estimate the quality of these and other systems, it is essential to have proper wave propagation models developed for the environment and situation of interest.
Furthermore, wave propagation models are important components in different radio planning tools.
There are two types of models, stochastic and deterministic models were the deterministic ones are the most interesting for military purposes and we have given examples of some available deterministic models. Above them, an earlier project at FOI Command and Control Systems, the Radio channel - Vegetation project, has studied radio wave propagation affected by vegetation. That project developed a model based on parabolic equation (PE) technique as reported by Holm and Eriksson [33]. The technique can be applied to wooded irregular terrain with good results and we will, during second half of 2003, investigate if the model is suitable for urban environment as well, at least for some situations.
Furthermore, free space optics (FSO) may have potential to become an alternative to radio communication in urban areas, due to less jamming and interception sensitivity, high bit rate (up to a few Gbps) and no licensing or frequency allocation needed. One of the limitations with free space optics, beside the atmospheric effects, is the need of line-of-sight. If the laser beam can reflect against a wall and preserve the information, it may be possible to overcome the line-of-sight restriction. We are planning to do some experiments on the subject and report the progress during the autumn 2003.

The Division of Sensor Technology, Department of Laser systems, together with the Army Combat School, has scanned the exercise area at Kvarn, Borensberg with laser radar. The data is transformed into a 3D model. The Army Combat School have added models of the buildings belonging to the training city that are going to be built in the area. They are also

about to add models of buildings to the enlarged training city that hopefully will be built in the area; decision about this will be made during 2004.
During the second half of 2003, we plan to expand the 3D model with some wave propagation model. The purpose is to simulate the radio wave propagation in the area and to demonstrate the wave propagation condition in urban areas.

In urban areas with large objects blocking the line-of-sight the multipath components, i.e. signal components that arrives at the receiver from many directions simultaneously, have a major contribution to the signal. Because of this, it is more and more interesting to use smart antennas and MIMO systems that can make advantage of the multipath situation. To model such a channel the multipath components are needed together with spatial information. We are planning, in collaboration with Lund University, Department of Electroscience, to perform measurements on the MIMO channel. The measurement campaign will start this autumn with a few test set-ups in the frequency range 2 GHz. The collaboration with Lund University has given us the opportunity to buy a measurement module for the militarily interesting frequency range around 300 MHz that will work together with the Lund University MIMO system. The MIMO capacity, for the 300 MHz module, is up to 16 transmitter and receiver antennas, though we will use 8 transmitter and receiver antennas. Measurements in urban areas and frequency range 300 MHz will start in 2004.

7 References

[1] Swedish Armed Forces, http://www.mil.se

[2] Ag GeTaS, Informationsscenario, bilaga 5, strid i stad, ATK 21 120:61006, 2002-12-18.

[3] Mj Walldén, Stridsteknik Strid i bebyggelse, Stridteknikenheten, Markstridsskolan, Kvarn, dec 2001.

[4] Studie MOUT 2010, Förslag till målsättning ”Militära operationer med land-, sjö- och luftburna markstridskrafter i urbaniserad terräng 2010-2015”, Stridteknikenheten, Markstridsskolan, Kvarn, 2003-01-30.

[5] Joint Tactical Radio System, http://jtrs.army.mil

[6] SAAB AB, http://www.saabtech.se

[7] Swedish Defence Materiel Administration, http://www.fmv.se

[8] J. Bergqvist, “Tryggare medborgare – säker kommunikation”, Statens offentliga utredningar, SOU 2003:10

[9] J. Rydh, “Ett tryggare Sverige”, Statens offentliga utredningar, SOU 1998:143

[10] European Telecommunications Standards Institute, http://www.etsi.org

[11] R. Pengelly, “The military goes broadband”, Jane’s Defence Weekly, September 2002.

[12] Defense Advanced Research Projects Agency, http://www.darpa.mil

[13] ITT Industries, http://www.itt.com

[14] L C Andrews, “Laser Beam Propagation Through Random Media, SPIE, vol PM53, 434 p, 1998.

[15] J.M. Kahn and J. R. Barry, "Wireless Infrared Communications", Proc. of the IEEE, vol. 85, 1997.

[16] B. Asp, G. Eriksson and P. Holm, (1997): DETVAG-90 – Final report, FOA-R—97-00566-504—SE.

[17] WinProp, documentation (2002) AWE Communications GmbH, Gärtringen, Germany. http://www.awe-communications.com/

[18] R. Vaughan and J. B. Andersen, (2003): Channels, propagation and antennas for mobile communications, IEE Electromagnetic waves series 50, London, UK.

[19] A. F. Molisch (2002). Modeling of directional wireless propagation channels, The Radio Science Bulletin, No 302, pp. 16–26.

[20] M. Steinbauer, A. F. Molisch and E. Bonek (2001): The double-directional radio channel. IEEE AP Mag., Vol 43 No 4, pp 51–63.

[21] Correia, L.M.(editor, 2001): Wireless flexible personalized communications (COST 259: European co-operation in mobile radio research), Wiley, Chichester, UK.

[22] Cátedra, M. F. and Pérez-Arriaga, J. (1999): Cell Planning for wireless communications. Artech House, Boston.

[23] Holm, P., Eriksson, G., Lundborg, B., Ladell, L. (2002): Belysning och strålgeometri för spridningsytor i terrängen. AerotechTelub K2-02:0576; FOI Memo Dnr 02-1111:1.

[24] Ladell, L., Eriksson, G., Holm, P., Lundborg, B. (2001): Bistatisk reflexion och spridning från en rektangulär platta. *AerotechTelub E017-KF-2001322; FOI Memo Dnr* 01-2142:1.

[25] Ladell, L. (2002): 3D deterministisk vågutbredningsmodell. AerotechTelub K2-02:0718; FOI Memo Dnr 02-1111:3.

[26] Lundborg, B., Ladell, L., Tronarp, O., Zeijlon, P., Thomasson, A. (2001): Modellstruktur och beräkningsmetodik för 3D kanalmodell. AerotechTelub K2-01:0374; FOI Memo Dnr 01-2142:7.

[27] Ladell, L., Thomasson, A., Lundborg, B. (2001): 3D vågutbredningsprogram för tätort: Förslag till handlingsprogram. AerotechTelub K2-01:0373; FOI Memo Dnr 01-2142:10.

[28] Löfsved, E., Thomasson, A., Ladell, L. (2001): Kommersiella programvaror för 3D kanalmodeller. AerotechTelub E017-KF-2001338; FOI Memo Dnr 01-2142:3.

[29] Thomasson, A. (2003): Modeller av stadsbebyggelse och antenner avsedda för kommersiella 3D vågutbredningsprogram. AerotechTelub K2-03:0675; FOI Memo Dnr 03-169:6.

[30] Radioplan Gmbh, Dresden, Germany. http://www.radioplan.com

[31] Remcom, PA, USA, http://raptor.remcom.com/wireless/

[32] WaveCall SA in Lausanne, Switzerland. http://www.wavecall.com/

[33] P.Holm, G. Eriksson, “Parabolisk ekvationsteknik för vegetation.” FOI-R--0637--SE, December 2002.