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# SIMCO3++: SImulation of Mobile COmmunications for Performance Evaluation of Cellular Networks, Short-Range and Satellite Communications

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*Abstract:* **In this paper a general tool for SImulation of Mobile COmmunication in C++ (SIMCO 3++) is presented. The tool is the result of research activities in several European projects within RACE and DRIVE and standarization activities (CEN TC 278, ISO TC 204, ETSI, etc.) in the field of mobile communications. The SIMCO 3++ tool is based on the object-oriented CNCL (Communication Networks Class Library) and contains simulation models for performance evaluation of communication protocols implemented in the following modules and functions: modelling of mobility, channel modelling and propagation, medium access schemes, handover schemes, location management and routing, data generation and queueing, random number generation and statistics. The simulation tool can be easily adapted to any mobile communication system and might therefore be of interest also for RACE III (ACTS) proposals.**

## 1. Introduction

SIMCO 3++ is used for performance evaluation by simulation for various mobile communication systems:
- Cellular Networks (GSM, UMTS, etc.);
- Mobile Broadband System (MBS);
- Cordless Tlecommunications (DECT, etc.);
- Packet Radio Networks (SuranNet, etc.);
- Short-range Communications;
- Satellite Communications

The tool is based on the CNCL (Communication Network Class Library), which is a C++ library consisting of all all necessary container classes for event driven simulation. SIMCO3++ offers all basic mobile communication models implemented in the following modules:

- *Modelling of Mobility*: Stations in the plane; very realistic motorway traffic scenarios; rural road scenarios; urban road networks; satellite tracks;etc.
- *Channel Modelling and Propagation*: Developement of various channel models for 5.8 GHz, 63 GHz narrowband (DSRC, COMIS), infrared (DSRC), 62/65 GHz broadband (MBS), Satellite channels (2.5 GHz); antenna characteristics; bit error rates; shadowing; multipath fading (based on raytracing); transmit power; etc.
- *Medium Access Schemes*: MA in GSM, DECT, MBS; DSRC layer 2 protocol (for vehicle roadside communications), DCAP, ICAR++, etc.; satellite channel access protocols.
- *Handover Schemes*: Handover in GSM, DECT, MBS.
- *Location Management and Routing*: Hierarchical and adaptive location management strategies; hierarchical and knowledge-based routing strategies.
- *Data Generation and Queueing*: Various codec schemes and queueing systems.
- *Random Number Generation and Statistics*: Uniform disributed random numbers: LCG, Lagged-Fibonacci, Tausworth Generator, etc.; continous distributed random numbers: normal distribution (Box-Muller, Dieter-Ahrens, etc.), exponential, Erlang, hyperexponential, etc.; confidence intervals, batch means, LRE (limited relative error) etc.
- *Simulation Techniques and graphical display*: CNCL objects; event-handling and scheduling; (interactive) graphical display GIST (Interviews, EZD).

The quite powerful simlation tool SIMCO 3++ takes into account realistic mobility scenarios and channel characteristics and allows the performance evaluation of a variety of systems currently being developed or standardized.

### 1.1. The Communication Networks Class Library (CNCL)

CNCL follows an object oriented concept which is aided by its implementation in C++. It therefore offers a good opportunity for easy programming and good program maintainance. Since C++ is an object oriented programming language which is generally recognized and available on most computer systems, the portability of the written code is ensured.

In contrast to many other C++ classes CNCL strruuctre is hierarchical (tree structure: i. e. all classes are derived from one basic class). This allows all derived classes to have a common set of member functions available. These functions provide runtime type checking and type information, creation of objects via class description and safe type casts.

The simulation library of CNCL contains:
- A general purpose C++ class library
- Event driven simulation
- SDL-oriented simulation

The CNCL contains classes for simulation scheduling, object and information handling, classes for communication, and classes for random number generation, distribution functions, and statistic analysis of simulation results.

### 1.2. The Graphical Interactive Simulation result Tool (GIST)

To control the functionality of the simulation and to graphically present the simulation results a Graphical Interactive Simulation result Tool (GIST) has been developed and is currently beeing further extended. It allows both the interactive online control of the simulation and the presentation of the simulation results in a postprocessing manner after simulation. The mobility scenario as well as the related parameters like CIR, BER etc. of all mobile stations can for example be displayed.

## 2. Short-Range Communications

In order to increase the efficiency and security of the traffic, new concepts and technologies for a future Integrated Road Traffic Environment (IRTE) are currently developed in various ATT (Advanced Traffic Telematics) and IVHS (Intelligent Vehicle and Highway Systems) Research & Development Programmes. The IRTE will require highly reliable, short-range mobile communications to exchange relevant information between vehicles and roadside beacons (Automatic Fee Collection, Route Guidance, Parking Management, etc.) and between vehicles (Intelligent Cruise Control, Intelligent Maneuvering Control, etc.) in free traffic flow.

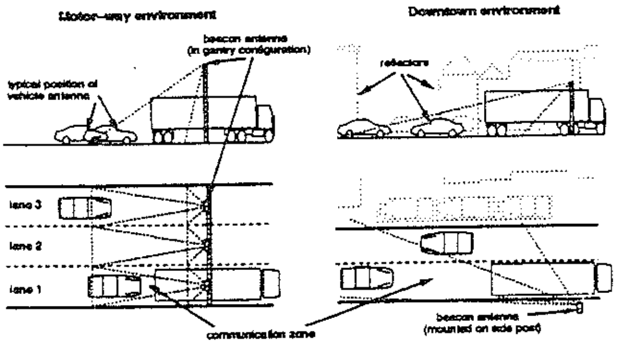


**Fig. 2.1: Different ATT scenarios**

For the development of high-performance communication protocols and the optimal selection of system components a number of requirements and constraints resulting from different applications, systems environments and transmission technologies have to be taken into account: e.g. the amounts of data to be transmitted (data packet size ranges from 50 bits up to several kbits) and the required reliability (for automatic fee collection a transaction error rate of $10^{-6}$ is required) vary considerably for different applications. The system environment has a strong influence on the characteristics of the traffic flow as well as on the quality of the physical channel: an automatic fee collection system on a motor-way has to cope with high traffic intensities and sometimes extremly high speeds, whereas in an urban environment the vehicle speeds are relatively low, but multi-path fading effects due to reflections of buildings, traffic signs, parked vehicles etc. may lead to a considerable reduction of the channel quality (see figure 2.1).

### 2.1 Concept of SIMCO3++/DSRC

Our approach for the performance evaluation of the communication protocols for the IRTE relies on stochastic, event-driven simulation in a realistically modelled environment. Based on the concept of the SIMulation of Mobile Communications (SIMCO) described in the previous section the simulation tool SIMCO3++/DSRC (Dedicated Short-Range Communications) has been developed. The simulator incorporates the following elements:

- A run-time efficient, microscopic traffic model, which is able to provide a realistic traffic flow in motor-way as well as urban scenarios by taking into account traffic statistics, driver behaviour and environmental conditions. In [4] the very good correspondence between measurement data from motor-ways and data, which has been generated by SIMCO3++/DSRC, has been shown.

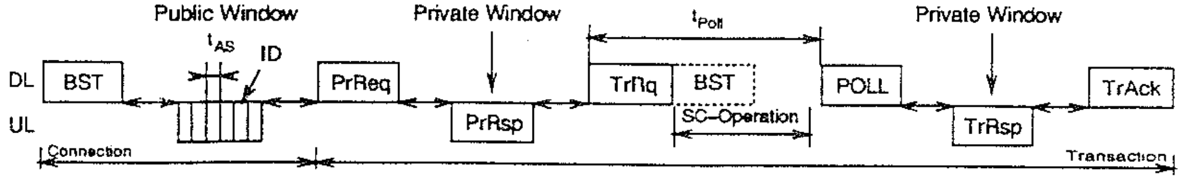


**Fig. 2.2: Timing diagramm of asynchronous protocol**

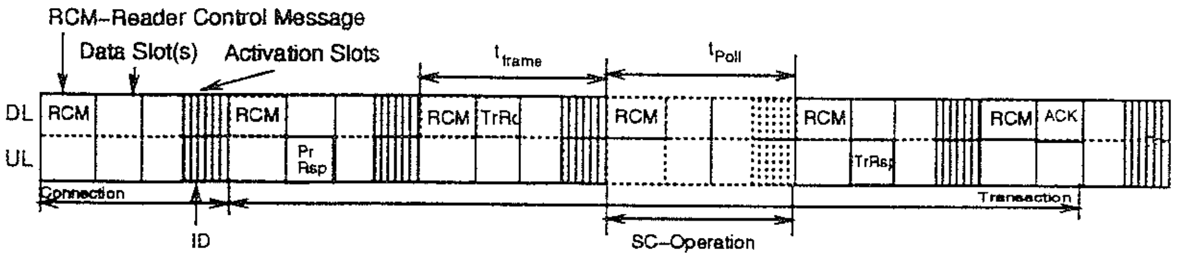


**Fig. 2.3: Timing diagramm of synchronous protocol**

- Antenna design techniques and a realistic model of the transmission channel taking into account multi-access and multi-path interference in a given scenario. In order to determine and optimise the channel characteristics in multi-path fading environments, synthesis techniques for linear array antennas (e.g. Fourier Transform method) have been combined with raytracing techniques [7].
- An implementation of the communication architecture/protocols (Physical, Data Link and Application Layer) and several application processes.

SIMCO3++/DSRC has been used in several DRIVE II projects (COMIS, GERDIEN) as well as for the extensive performance evaluation of different options of medium access protocols proposed for standardisation (CEN TC 278 WG9.SG.L2) (see example below).
Furthermore tools specialised on medium access protocol performance evaluation are available: SIMCO-F(ast) with reduced mobility/channel model but accurate implementation of the protocol options and MARCO (Performance analysis of Medium Access Control Schemes for Roadside COmmunication using MARkov models taking into account all options for the DSRC Layer 2 standard).

## 2.2 Performance Evaluation of MAC-Protocols with SIMCO3++/DSRC

As an example for the use of SIMCO3++/DSRC, in this paper the results of a performance analysis of an asynchronous protocol proposed by the European standardisation group (CEN TC 278 WG 9.SG.L2) in comparison with a synchronous protocol, which was developed within the American IVHS programme (Open Road Frame, [5]), are presented. The timing diagrams of both protocols are given in figures 2.2 and 2.3 for an automatic fee collection application process (a detailed description is given in [6]). A motorway scenario with high traffic intensity and three lanes has been chosen as reference scenario. The communication zone of 6 m length comprises all three lanes; a bit error rate of $10^{-6}$ for 500 kbit/s transmission rate in both directions has been assumed. The simulation results are given in figure 2.4 and figure 2.5, which show the

- non-completion rate (ratio between the number of vehicles, which could not complete the transaction, and the number of vehicles, which entered the communication zone) versus
- the normalized communication zone (ratio between the communication zone, which was needed by the vehicle to complete the transaction and the available communication zone).

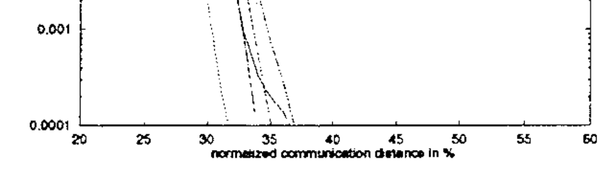


**Fig. 2.4: Results: Asynchronous protocol**

The following characteristic results are shown:

(i) reference curves: no collision recovery scheme used (single slot public window/activation slot, transmission probability set to 1) and an ideal curve (no data collisions)

(ii) variable frame/asynchronous protocol: public window with public windows with different numbers of slots (2 to 16)

(iii) fixed frame: different combinations of data slots (2 and 4) and activation slots (2 to 16)

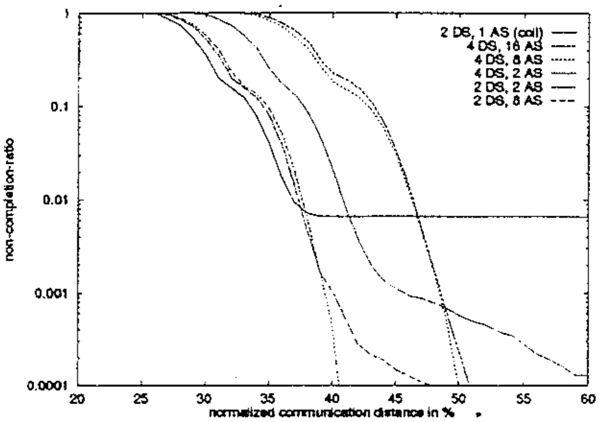


**Fig. 2.5: Results: Synchronous protocol**

The comparison of the results presented above show, that the fixed frame structure produces a considerable overhead for applications such as Automatic Fee Collection. The variable frame protocol achieves best results for multiple-slot public windows with at least 8 short (0.15 ms) slots. Using these parameters, the variable frame option does better than the fixed frame option as it is more flexible.

## 3. SIMCO3++ for Cellular Networks

The SIMCO3++ tool has been developed for protocol performance evaluation (medium access [8], handover [9], location management [10], routing [11], etc.) of mobile cellular and cordless systems, especially:

- Mobile Broadband System (MBS) [12]
- GSM (Global System for Mobile Communications)
- Digital European Cordless Telecommunications (DECT) [13]
- etc.

Due to similar functionality only the system simulation aspects of MBS are described in more detail in the following.

### 3.1 SIMCO3++ / MBS

The RACE II MBS-Project addresses the system concepts, the techniques and technology (especially GaAs MMIC, i.e. millimeter-wave monolithic integrated circuits) required for the transition to the "Mobile Broadband System (MBS)", which will fill the gap between between the fixed B-ISDN and the 3rd generation Universal Mobile Telecommunica-tion System (UMTS). This will extend to mobile users access to the range of broadband services, which either exist or will exist for fixed users.

A major characteristic of the MBS is, that it will allow to transport ATM cells (asynchronous transfer mode) over the air interface at bit rates above 2 Mbit/s, but it will also offer lower bit rates as for UMTS. High bit rates over 34 Mbit/s can be realized by using parallel frequency channels. To provide an easy interference free frequency reuse every few kilometers, the 60 GHz band, with a maximum of propagation attenuation due to oxygen absorbtion, has been proposed by CEPT for MBS. The recommended frequency band for MBS is divided into two subbands, 62-63 GHz and 65-66 GHz, allowing full duplex transmission.

### 3.2 60 GHz Propagation Modelling using Raytracing Techniques

To investigate sensitive system characteristics like

- delay spread
- multipath propagation resulting in fading holes caused by destructive interference
- received signal strength
- Doppler shift
- etc.

and to develop an appropriate 60 GHz radio channel model for MBS, raytracing techniques have been implemented in SIMCO3++, taking the following environmental conditions into account:

- Base station location
- line of sight path (LOS)
- single and double reflected path
- position and shape of environment objects (walls, windows, obstacles, etc.)
- reflection areas
- reflection coefficient depending on angle of incident.

Fig. 3.2-1 shows a typical indoor scenario (e.g. office) with three large windows, several obstacles, the position of the base station and the marked route of a mobile station.

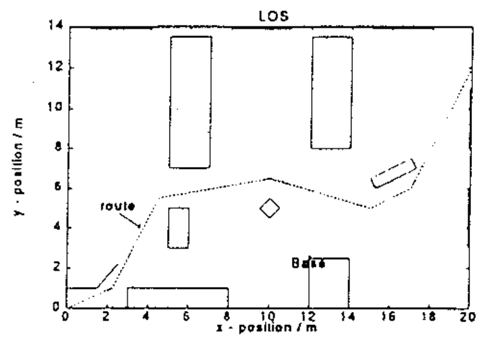


Fig. 3.2-1: Indoor scenario (office) and LOS area

In the following two figures the received signal strength along the marked route and the number of rays taken into account for each position are shown. In Fig. 3.2-2 only single reflected paths were taking into account, while Fig. 3.2-3 shows the results also from double reflections.

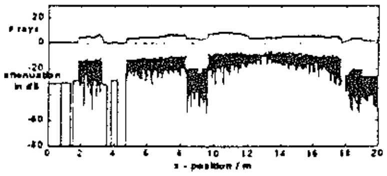

Fig. 3.2-2: Attenuation along marked route, single reflections only

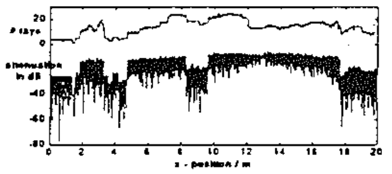

Fig. 3.2-3: Attenuation along marked route; double reflections

Fig. 3.2-4 shows the attenuation of the whole indoor scenario for a height of 1.5 m above the ground. For further performance evaluations of medium access control schemes, (refer to [8] for details) and appropriate handover algorithms (see [9] for details) using the SIMCO3++ simulation tool, a statistical propagation model based on a tapped delay line model is currently developed and implemented in SIMCO3++ / MBS, which takes the results of the calculated propagation characteristics into account. This model is based on statistics retrieved from a large number of different indoor / outdoor scenarios using the raytracing facilities of SIMCO3++ as described above. As an example, the probability density fuction and the cumulative distribution function of the the delay spread of the indoor scenario above are shown in Fig. 3.2-5 and Fig. 3.2-6 resp.

The 60GHz statistical propagation model for MBS based on raytracing techniques will be compared with results from indoor and outdoor 60GHz channel measurement campains for further refinement of the 60GHz broadband channel model.
The performance evaluation of location management strategies and routing algorithms for MBS using the SIMCO3++ simulation tool are described in detail in [10] and [11] of this proceedings.

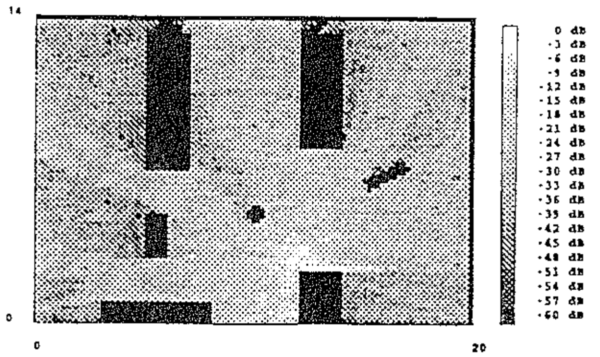

Fig. 3.2-4: Attenuation in a height of 1.5m above ground

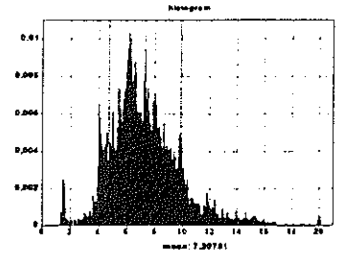

Fig. 3.2-5: Probability density function of delay spread

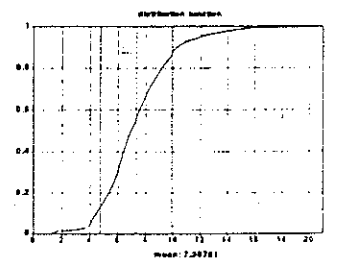

Fig. 3.2-6: Cumulative distribution function of delay spread

# 4. SIMCO 3++ for Satellite Communications

## 4.1. Introduction

Considering third generation mobile systems (UMTS/FPLMTS) as *universal systems*, it is considered of primary importance to recognize the satellite component as a complementary component of the terrestrial segment. The satellite component will be necessary in order to ensure full coverage of the UMTS system. This deals with coverage of rural areas, where a cellular network implementation would not be cost effective or coverage of underdeveloped coutries enabling to bypass old telecommunication infrastructures. Furthermore, the inherent flexibility of the satellite will be of prime importance when considering the highly dynamic traffic conditions characterising mobile networks. The primary objective of the RACE II - project SAINT will be the integration of satellites into UMTS [1].

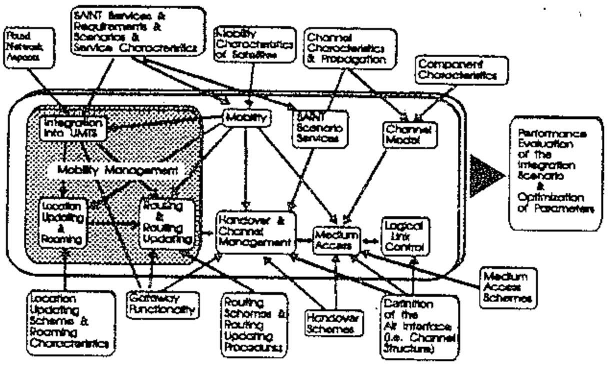


Fig. 4.2.1: Basic Simulation Model

In order to provide worldwide coverage of UMTS-services, various integration scenarios and satellite system topologies are going to be investigated. Computer-simulations are essential for satellite system design concerning: performance evaluation of new developed satellite-segment communication protocols for medium access, handover, radio resource management and mobility management, their integration functionallity and optimization of parameters under various environmental conditions.

Therefore, the simulation tool SIMCO 3++ for integration scenario evaluation and for performance evaluation of communication protocols is currently further extended and adapted to the specific characteristics of satellite communications.It is intended that the SIMCO 3++/SAT will be based on realistic models of satellite- and user-mobility, propagation and satellite channel models.

## 4.2. Basic Simulation Model for Satellite Communications

Due to the complexity of system design of DCSSs (Dynamic Constellation Satellite Systems), high mobility of users and considering various integration scenarios of the satellite segment of UMTS, results obtained from computer-simulations, which are based on an appropriate channel model (including doppler, fading, multi-path), will be essential for the development and refinement of protocols for the UMTS/SAINT system. Therefore a basic simulation model is required, which allows the integrated and standalone simulation of all important functions such as handover, channel management, medium access and mobility management (location updating, routing, interworking). Fig. 4.2.1 shows the basic modules of such a simulation model and their interdependancy.

In order to obtain realistic simulation results it is essential to first define a realistic traffic load. This load can be obtained by evaluating apropriate field trial measurements of already existing systems or by assuming statistical traffic for future services and mobility behavior of both the terminals and the chosen satellite scenario. Second, one has to derive a statistical channel error model taking the influence of doppler shifts, fading, multi-path propagation and shadowing as well as enviromental conditions into account.

Based on this, the SIMCO 3++/SAT tool will take into account specific requirements concerning the integration aspects into UMTS of the chosen satellite scenario. Therefore several integration scenarios can be compared based on their simulation results and the advantages and disadvantages can be analysed.

## 4.3. Scenario Implementation

As mentioned in 4.2. it is essential to define a realistic traffic load for the simulation tool. In order to do so various integration scenarios have to be defined prior. The role of the satellites and the gateways as well as the set of user services available at the terminal have to be defined for each integration scenario.

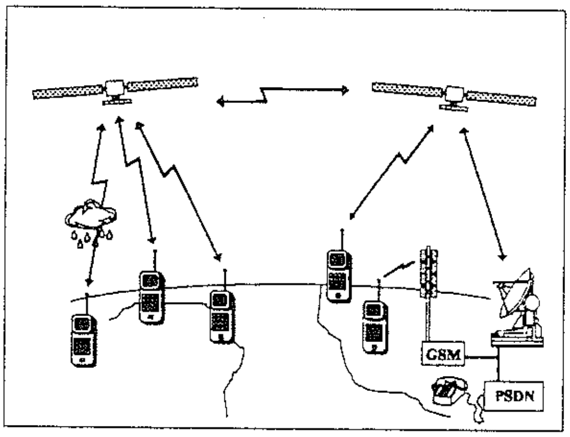


Fig. 4.3.1: Sample Integration scenario

One of the possible scenarios allowing mobile user links (MUL) as well as inter satellite links (ISL) and gateway links (GWL) is shown in 4.3.1..

With the SIMCO3++/SAT tool this scenario could be analysed and information about the chosen mobility (i.e. coverage) or for example the signal propagation from the satellites to the mobile user could be obtained.

## 5. Conclusion

The current state of SIMCO 3++ as well as its extension towards a SIMCO 3++ SAINT tool were presented in this paper. Due to its modular structure and its object-oriented design the SIMCO 3++ simulation tool allows the performance evaluation of many different cellular networks (GSM, DECT, UMTS, MBS) as well as the study of system integration as proposed in SAINT. Due to the fact that it can be easily adapted to many other communication network types it is desirable to extend its use in future RACE III (ACTS) projects.

## Acknowledgement

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