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Model-Based Geo-Simulation Approach for Performance Evaluation of 1xEV-DO

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Abstract

The performance of a mobile network is essentially based on the capacity of its radio access technology. A mobile network is spatially and functionally distributed. Its subsystems are in constant interaction with each other and with their geographic environment. Finding an appropriate approach to evaluate the capacity of a radio access technology with respect to a wide range of parameters (radio signal quality, quality of service, user mobility, and network resources) has become increasingly important in today's wireless network planning. Traditional mathematical and statistical modeling techniques do not satisfy the requirements of such a complex process where spatial data is of fundamental importance. In this paper, we propose a model-based geo-simulation approach in order to assess the capabilities of the 1xEV-DO radio access technology. Results are expressed in terms of signal quality (C/I and E_C/I_0*) for the requested services and applications.*

1. Introduction

The 1xEV-DO (EVolution Data Only) radio access technology promises interesting data throughputs and simultaneously provides coexisting voice and data services within the same radio frequency (RF) [5], [8], [10]. The necessity of having an efficient approach to evaluate the performance of such radio access technology in wireless networks is rapidly growing alongside the evolution of standards and technologies [3]. Such approach must take into account a wide range of parameters, such as radio signal quality, quality of service, user mobility and network resources [6], [7].

This paper presents a model-based methodology designed in order to assess the capabilities of 1xEV-DO radio access technology. It is organized as follows. Section 2 provides an overview of the technical characteristics of the 1xEV-DO radio access method. Section 3 exposes the problem of performance evaluation addressed in this paper. Section 4 presents the proposed model-based geo-simulation approach. Section 5 describes the implementation and the simulation results, whereas Section 6 gives some concluding remarks.

2. Technical Overview and Background

1xEV-DO optimizes both data delivery and spectrum efficiency by using a number of techniques that are based on the channel structure, the multiplexing method, the scheduling algorithm, and H-ARQ [1]. This section investigates such schemes for both forward and backward links. As illustrated in Figure 1, the forward link of 1xEV-DO consists of a pilot, traffic, medium access, and control channels which are allocated to different users in the time domain [4]. The pilot is transmitted with the user data to enable coherent reception, soft handoff, channel estimation, long-range prediction and rate selection. The medium access channel consists of two CDM channels: the reverse activity (RA) and the reverse power control (RPC) channels. The RA channel is used to indicate the activity status of the reverse link, i.e., the interference level in the sector, whereas the RPC channel is used for the fast power control of the reverse link connections. The control channel is used for system acquisition, system parameter broadcast and service negotiations during call setup. The traffic channel transmits data to multiple users in a time-division multiplexing (TDM) fashion. Each frame has a duration of 26.67 msec, and is divided into 16 slots (1.667 msec each). As a result, the transmission of one frame can occupy from 1 to 16 time slots. Each slot contains a 96 chip pilot burst which is centered at the mid point of ½ slot, and is assigned to users by a scheduling algorithm according to the best instantaneous radio conditions. Figure 2 illustrates the structure of 1xEV-DO time slot [6], [12].

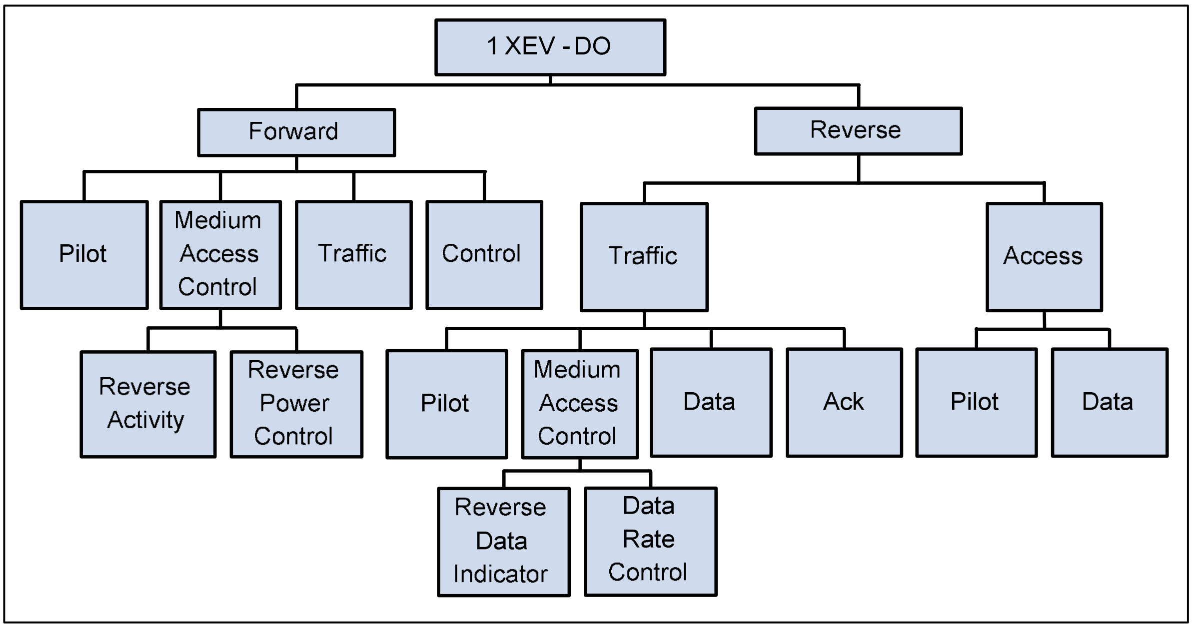

Figure 1. 1xEV-DO channel structure

Another important feature of the 1xEV-DO forward link is the use of scheduling algorithms that exploit multi-user diversity and fading to increase throughput [1], [2]. Even if the EV-DO standard does not explicitly specify a scheduling algorithm, the proportional fair scheduling constitutes an appropriate compromise between maximizing the system capacity and achieving fairness among users [11]. Under static channel conditions, this algorithm provides equal transmission time to active users by maintaining their throughputs proportional to static data rate control (DRC) they request, whereas, in a fading environment, it allows the scheduler to prefer a user whose channel becomes favourable for a short period of time during “up-fade” indicated by the high DRC value, while delaying data transmission to the user who is temporarily in the “down-fade” relative to its average condition.

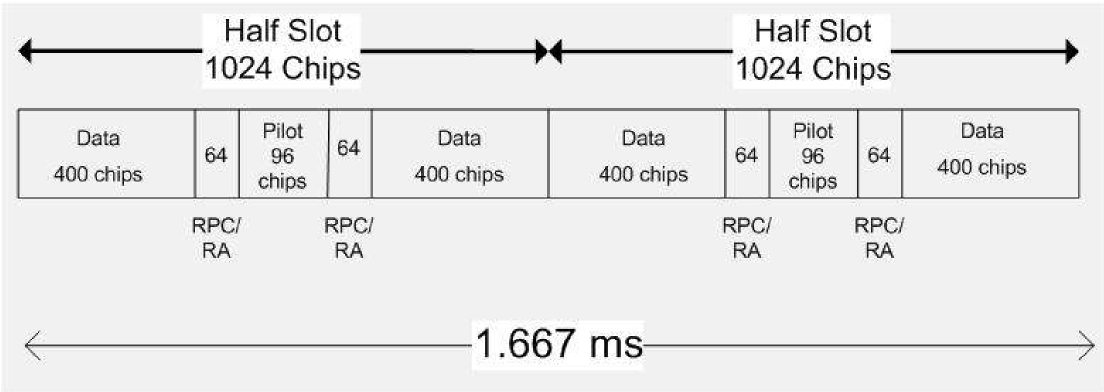

FIGURE 2. STRUCTURE OF 1XEV-DO TIME SLOT

Moreover, the EVDO system uses quick adaptive modulation and coding (AMC) to optimize data rates, subject to the radio link quality. Based on the C/I ratio, measured from the received signal in every time slot, the mobile terminal determines the data rate that can be supported on the forward link in its current conditions, as well as the best serving sector. The C/I ratio and the data rate are related as follows [11]:

$$\frac{C}{I} \times \frac{W}{R} = \frac{E_b}{I_0 + N_0}$$

Where W is the spreading bandwidth and R the data rate. As a result, given the required value for a particular combination of modulation and coding scheme, the supportable data rate may be estimated as follows:

$$R = W\left(\frac{C}{I}\right) \Big/ \left[\frac{E_b}{I_0 + N_0}\right]$$

More specifically, when an 1xEV-DO device is operating with low signal and high interference levels, a robust modulation type (e.g. QPSK) is used. The type of modulation and subsequent data rates can change every 1.67 msec. In the same vein, dynamic coding employs different levels of forward-error correction to maximize the reliability of data transmission with significant reductions in added overhead. As a result, high data rates are achieved through a good combination of high order modulation (QPSK, 8-PSK and 16-QAM), FEC coding (r = 1/5 and r = 1/3) and spreading factor. Such combination determines one of the 12 rate configurations summarized in Table 1 [1], [2]. Under optimal conditions, EV-DO may offer average throughputs of 300 kbps to 500 kbps and peak rates of 2.4 Mbps.

Furthermore, to enable fast AMC and improve throughput, EV-DO also uses H-ARQ, combining failed transmission attempts with the current attempt, and making the initial modulation and code rate selection process tolerant to selection errors. Two fundamental forms of H-ARQ are: chase combining and incremental redundancy (IR) [4]. In chase combining, each retransmission repeats the first transmission or part of it. In IR, each retransmission provides new code bits from the mother code to build a lower code rate. While chase combining is sufficient to make AMC robust, IR is especially helpful in the situations where accurate channel prediction is not possible, for example, at high speed or when other cell interference is highly variable. It offers the potential for better performance with high initial code rates, at the cost of additional memory and decoding complexity.

Moreover, the reverse traffic channel of 1xEV-DO is illustrated in Figure 3, and contains a pilot channel, a MAC channel, an ACK channel and a data channel [13]. It consists of two information streams: the *I* phase and the *Q* phase. The *I* phase transfers the pilot channel, return rate indicator (RRI), and user acknowledgement signals. The *Q* phase transfers the user data and the data rate channel (DRC). The pilot is used to enable coherent demodulation and tracking. The RRI informs the base station the data rate being transmitted on the reverse link. The ACK is used for early termination, whereas the DRC indicates the transmission rate that can be supported by a specific terminal. Each channel uses fixed-size physical packets.

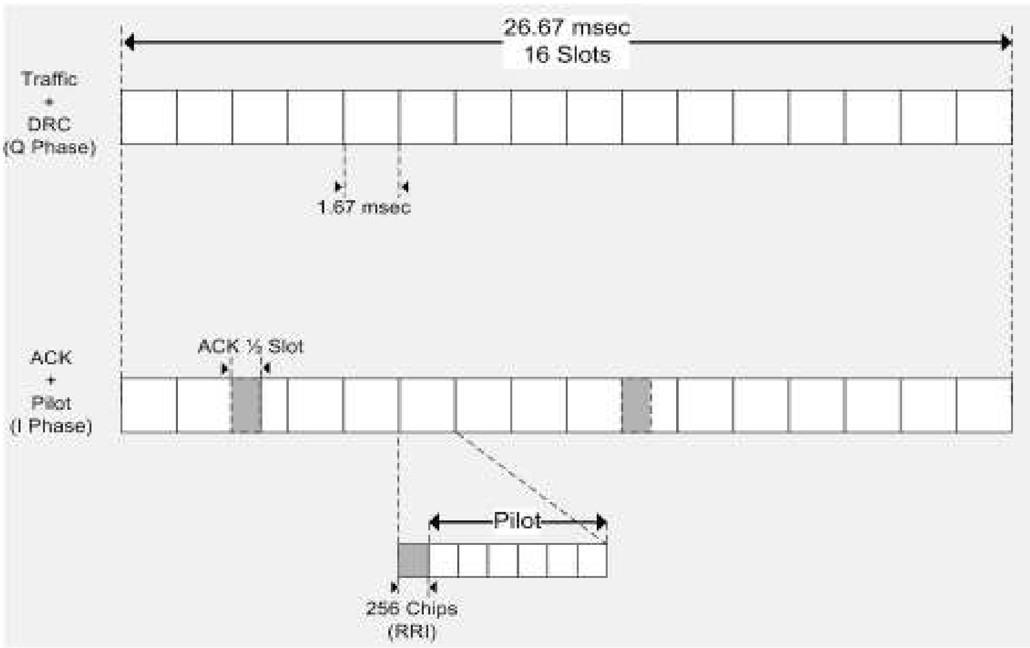

FIGURE 3. REVERSE CHANNEL OF 1XEV-DO

The radio access technology 1xEV-DO continues to evolve in order to provide higher data rates in both downlink and uplink, which is possible through the use of more efficient modulation technologies and increased channel bandwidth. Several papers attempted to evaluate the performance of 1xEV-DO from an analytical point of view [3], [8], [10], [14], [15]. However, such evaluation which includes various parameters, such as user mobility, radio interference, mobile terminal characteristics and quality of service of advanced applications, seems to be complex, and are not obviously feasible. That motivates us to propose a model-based geo-simulation approach which ensures that each parameter in a real network is taken into account and in particular the geographic environment.

2. Problem Formulation

The performance of a mobile network is essentially based on the capacity of its radio access technology [1], [4], [5], [17]. The prediction of the mobile network performance is a fundamental step in the capacity planning of such a system [17] [18]. Few papers have addressed the problem of radio access technology performance evaluation from an analytical point of view [2], [6], [9], [11], [12]. However, the increase of the parameters that must be considered to achieve a realistic evaluation leads to a complex mathematical system.

Moreover, the formulation of a mathematical model, which includes various factors, such as the user mobility, the radio transmission inference factors, the mobile device characteristics and the advanced applications qualities of service, seems complex and not obviously feasible. The complexity of the formulation and the resolution of such analytical models motivated us to find an alternative approach that addresses the performance evaluation of 1xEV-DO radio access technology while taking into account the abovementioned parameters and factors. Hence, we propose a model-based approach in order to include these different parameters and to permit, after model validation and calibration, to obtain realistic results. The obtained results demonstrate the 1xEv-DO capabilities to satisfy the user request based on the measured signal quality rates *C/I (dB)* and E_C/I_0 *(dB)*.

3. Model-Based Simulation

The proposed model-based simulation consists of two phases: the specification of radio and geographical environments, as well as the definition of a set of models related to the traffic.

3.1 Environment Specification

This phase consists of specifying the parameters that characterize the environment of the mobile network. In this context, two sets of parameters are introduced: the radio parameters and the geographical parameters.

3.1.1. Radio parameters: The radio parameters represent a set of parameters that describe each site of the wireless infrastructure, i.e. the radio transmitters, the antennas and the sectors. More specifically, the radio transmitters are characterized by the type of antenna (120° beamwidth antenna), the downlink minimum power (DL Min Power), the uplink maximum power (UL Max Power), the signal transmission strength (Total Power), as well as the pseudo noise offset and the azimuth direction of transmission (Table 1). As for the antennas, they are characterized by three main parameters: the radio diffusion horizontal pattern (*RD Horizontal Pattern*), the radio diffusion vertical pattern (*RD Vertical Pattern*), and the angle between the half-power (3 dB) points of the main lobe [17]. Figure 4 illustrates such patterns, as they are plotted on the same scale to illustrate the differences in signal strength on the two planes. Moreover, a triple 120°-sector pattern is adopted to optimize the site coverage. Each sector is characterized by the maximum power control (*dBm*), the pilot channel power (*dBm*), the paging channel power (*dBm*), the synchronization channel power (*dBm*), as well as the uplink/downlink upload factor (%). The pilot, paging and synchronization channels constitute the fundamental channels to establish a wireless connection between mobile terminals and base stations [17]. The upload factor on both uplink and downlink expresses the capacity of each sector to satisfy simultaneous user requests [17].

TABLE 1. EXAMPLE OF TRANSMITTER IMPLEMENTATION

Parameter	Description
Antenna	120 Sector 14.5 dBi 0 Tilt
Transmission Noise Figure (dBm)	8
DL MinPower (dBm)	30
ULMax Power (dBm)	75
Total Power (dBm)	90
PN Offset	30
Azimut()	120

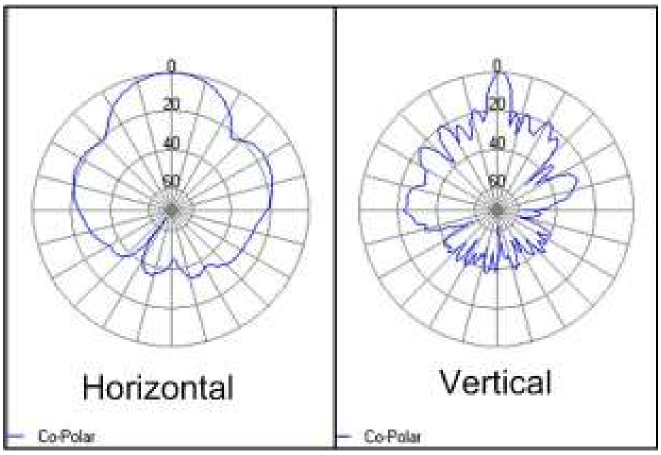

FIGURE 4. RADIO DIFFUSION PATTERNS (HORIZONTAL AND VERTICAL)

3.1.1. Geographical parameters: To guarantee a realistic simulation, we create a virtual geographic environment where the mobile network will be deployed. This area is represented by a digital terrain model (DTM) which encapsulates information on a 16 bits/pixel format. This computer graphic technique converts point elevation data into terrain model displaced as a three-dimensional map. Within this area, a more restricted area is defined and called *computation zone*, as illustrated in Figure 5. This restricted area is considered for the whole simulation process. It contains the sites for the transmitters, as each site is characterized by its position (x and y), its altitude, as well as the equipment it supports.

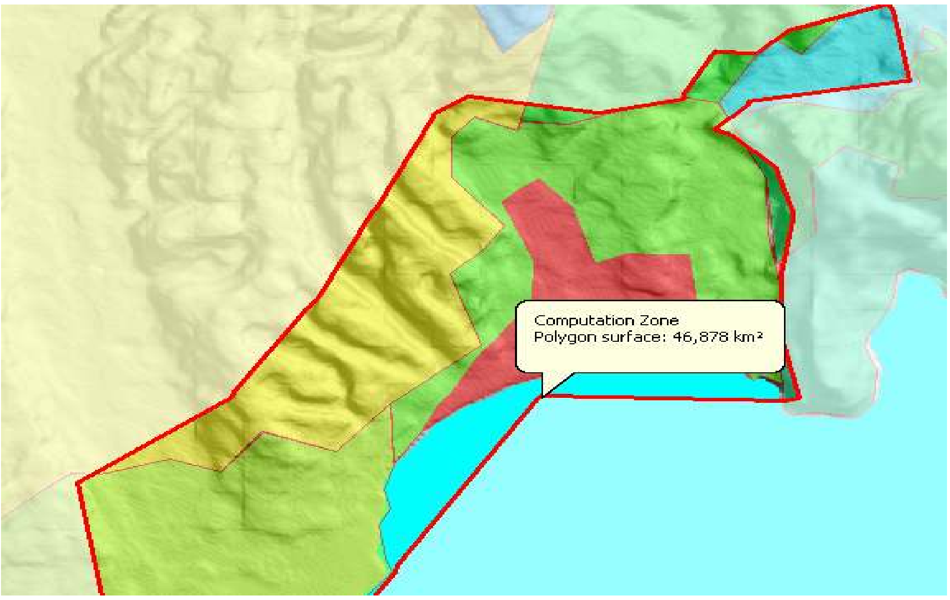

FIGURE 5. VIRTUAL GEOGRAPHIC ENVIRONMENT

3.2. Models Specification

A set of five models which reflect the dynamic of a real wireless communication system is given based on the following components: (1) *Mobility Model*; (2) *Mobile Device Model*; (3) *Service Model*; (4) *User Profile Model*; (5) *Traffic Model*.

3.2.1. Mobility Model: User mobility during the communication rises directly from the mobile networks definition itself. Thus, the representation of this data is fundamental to characterize the users according to their mobility patterns. The mobile terminal reception quality decreases according to the user movement speed and direction. The mobility model, in addition to the user mobility speed (m/s), is related to the signal quality rate (E_C/I_0) threshold (dB). It is also related to the pilot required power (dB) as well as the downlink *C/I* signal quality rate (dB). Table 2 illustrates the Mobility Model parameters.

TABLE 2. MOBILITY MODEL

Parameter	Description
Ec/Io threshold (dB)	Active-set management
UL Ec/Nt (dB)	Pilot required power
DL data rate by C/I (dB)	Mapping between Data Rate and C/I
Speed mobility (m/s)	Speed expressed in meter / second

3.2.2. Mobile Device Model: Users of the future mobile systems will be equipped with devices dedicated to support the services and advanced applications offered. The representation of the mobile terminals through a clean model within our methodology is justified. The terminal device plays an active role in the analysis of the reception signal quality. This model, through parameters relating to power losses and the minimum and maximum supported capacities, makes it possible to define the diagram of an adaptive coding and modulation (AMC) to reach an optimal transmission. Table 3 presents the data which identifies the Mobile Device Model.

TABLE 3. MOBILE DEVICE MODEL

Parameter	Description
Min Output Power (dBm)	Minimum Output Signal Power
Max Output Power (dBm)	Maximum Output Signal Power
Gain and Reception Losses (dBm)	The gain and the losses sown by wireless equipments
Noise Figure (dbm)	The ratio of the noise generated by the actual receiver to the noise output of an “ideal” receiver with the same overall gain and bandwidth

3.2.3. Service Model: Future mobile networks will offer large panoply of advanced services based on data transmission concept. Modeling advanced services and applications makes it possible to simulate the behavior of the network, which must take into account the service requirements in term of quality of service. The parameters for the service model as summarized in Table 4 are: the uplink activity factor (%), the downlink activity factor (%) and the service priority. We propose the modeling of the following services: Mobile Internet Access (MIA), Multi Media Messaging Service (MMS) and Videoconference.

TABLE 4. SERVICE MODEL

Parameter	Description
UL Activity Factor (%)	Uplink activity factor rate
DL Activity Factor (%)	Downlink activity factor rate
Service Priority	The service priority [0..1]
DL Eb/Nt (dBm)	Downlink Eb/Nt power
UL Eb/Nt Power control range	Uplink Eb/Nt power control range

3.2.4. User Profile Model: The user profile model provides a categorization of mobile users. This categorization is based on social and economical criteria, which are retrieved from GIS data. The user profile enables the evaluation of the user distribution in the network. In this context, two classes of users are defined: standard users and business users. Each class is characterized by the following parameters: the mobile device class or category (3G, 3.5G), the service activity, i.e. the average number of calls per hour, and the average call duration. Moreover, the user profile model is important for evaluating the speed and direction of each mobile user. Such a parameter has an impact on the received signal quality, which is taken into account by the active set. The active set makes it possible to define a set of base stations to which the mobile device can eventually be connected during a given period. Using the active set, connections with the best signal quality are offered to the mobile terminal during the user movement. The criteria that control the active set are related to the level of the signal quality. Such level is expressed in terms of required power for the pilot, downlink throughput (bps), and speed mobility (m/s). Table 5 presents the characteristics of the User Profile Model.

TABLE 5. USER PROFILE MODEL

Parameter	Description
Mobile Device Class	Mobile Device Category (2G, 3G)
Service Activity/Hour	Average of calls per hours
Time (s)	Average call duration

3.2.5 Traffic Model: The traffic model takes into account the mobile device types, as well as the services requested in each cell and the user profiles. In the context of this research, the mobile devices are dedicated to support advanced services and applications, such as mobile Internet access, multimedia messaging services (MMS) and videoconferencing. Such equipments are represented by a model that takes into account the received signal quality, which is expressed in terms of the minimum output power (*dBm*), the maximum output power (*dBm*), the signal loss (*dB*) and the noise figure (*dB*). Table 6 illustrates the parameters which characterize the Traffic Model.

TABLE 6. TRAFFIC MODEL

Parameter	Description
Geographic Zone	Computation zone
User Profile	User profile class
Mobility Type	Mobility type class
Density	User/Km^2

4. Implementation and Results

In order to implement the specified models and run the simulations we have adopted Atoll® tool. Atoll includes an advanced software development kit (*SDK*) which supports geographic information system features and multi-service traffic modeling. The region of Nice in France is chosen to simulate the coverage area, as illustrated in Figure 2.The basic parameters which characterize 1xEV-DO are defined and initialized with their default values. The quality of cell coverage is deeply related to the antenna propagation patterns. From such information, transmitters and their associated sectors are created and implemented on designated site locations. The distribution of geographical site locations is based on elaborate studies concerning the coverage area and the terrain topology. The virtual mobile network consists of 42 sectorized cells.

For implementing the set of models, we consider that mobile users are randomly distributed inside the computation zone in function of their profile models, in terms of mobility, traffic, services and density. From these models, we create a set of scenarios by varying certain parameters in order to figure out specific features of 1xEV-DO performance. Each scenario is characterized by a number of mobile users whose profile, mobility and density are randomly specified. Also, the assignment of terminals to mobile users is done in function of the user profile and the required services. Table 7 summarizes the experimental plan of the model driven simulation.

TABLE 7. EXPERIMENTAL PLAN

Parameter	Description	Value
Mobile Users	Number of Mobile Users	1200
Area	Nice city (France)	MapInfo (height and traffic maps, Nice city, France)
Cells	Number of cells	42
Simulation Runs	Number of simulation runs	21
Sectors	Number of sectors / cell	3

Simulation results illustrate the relationship between the requested service and the measured signal quality rates. Such results characterize the capacity of 1xEV-DO to satisfy user requests based on the allocated radio resources. Figures 6 and 7 illustrate how 1xEV-DO satisfies traffic requirements on both uplink and downlink, as they indicate the required and the offered throughputs. In Figure 6, the increase of the requested data rate (throughput) leads to the increase of the *C/I* (dB) signal quality rate.

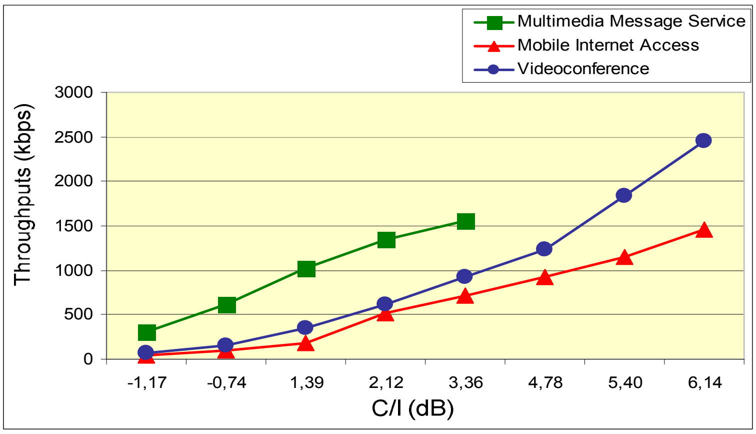

FIGURE 6. THROUGHPUT VERSUS *C/I* SIGNAL QUALITY RATE BY REQUESTED SERVICE

The same behavior is observed in Figure 7 where the increase of the requested data rate leads to the increase of the E_C/I_0 (dB). To obtain simulation results for 1xEV-DO channel signal to interference ratio E_C/I_0, the following formula is used for computation [13]:

$$\frac{E_c}{I_0} = \frac{a_0 P_0(\theta_0) L(\theta_0, d_0) G}{I_b + I_n + I_w + I_m + I_i + N}$$

Where:

$I_0 = P_0(\theta_0) L_0(\theta_0, d_0) G$: Interference power received at the mobile device from the overhead power emitted by the serving base station.

I_n : Non CDMA signal.

$I_w = G \sum_{k=1}^{K} P_k(\theta_k) L_k(\theta_k, d_k)$: Sum of the overhead powers from other base stations.

K : Total number of sectors in the system.

$I_m = G L_0(\theta_0, d_0) \sum_{j=1}^{J} T_j(\theta_0)$: Total traffic channel (Fundamental Channels (FCHs) + Supplemental Channels (SCHs)) power from the serving base station received at the mobile device.

J : Total number of mobile devices in the system.

$T_j(\theta_0)$: The Traffic channel *ERP* intended for the mobile device *j* but intercepted by the mobile device *0*.

$I_i = G \sum_{k=1}^{K} X_k(\theta_k) L_k(\theta_k, d_k)$: Total traffic channel power from all the other base stations.

N : Thermal noise power.

$P_0(\theta_0)$: The serving base station overhead ERP in the direction θ_0.

a_0: Fraction of the serving base station overhead ERP allocated to the pilot power.

$L_0(\theta_0, d_0)$: Path loss from the serving BS in the direction θ_0 to the mobile device located in a distance d away.

G : Receive antenna gain of mobile device.

Depending of the value of the signal quality rate (*C/I* or E_C/I_0) the mobile user's service request may be rejected. In this context, two fundamental types of rejection can be defined:

- Total rejection, *i.e.* the mobile user is not able to establish a radio connection with the system because of resource unavailability, which leads to connection rejection;
- Partial rejection, *i.e.* even if the offered throughput is not sufficient for an optimal run of the required service; it is possible to load such service with reduced quality of service.

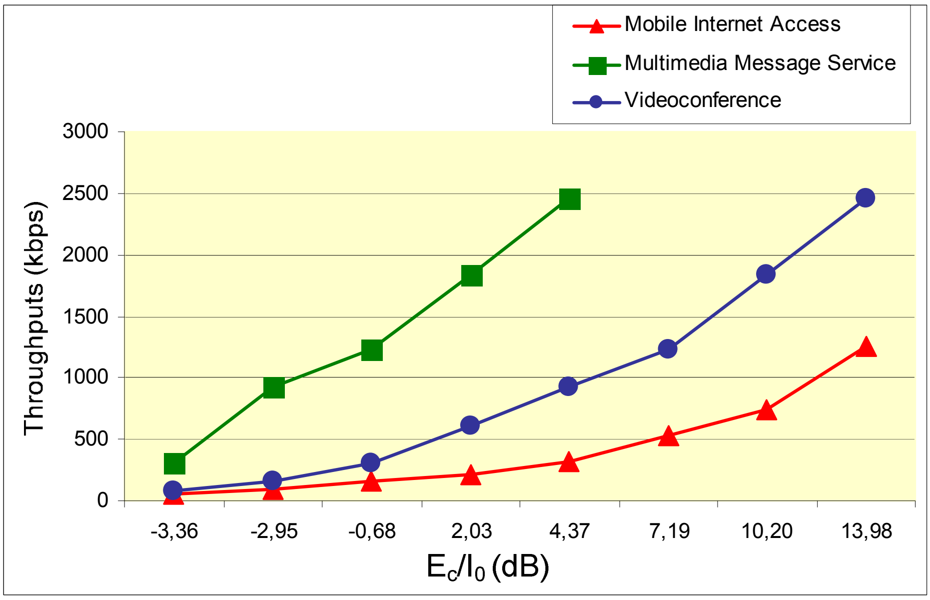

FIGURE 7. THROUGHPUT VERSUS E_c/I_0 SIGNAL QUALITY RATE BY REQUESTED SERVICE

From those results, we also observe that the user profile, which is more likely to be rejected, is the one who requires important radio resources. Videoconferencing is an advanced application with a high quality of service constraints.

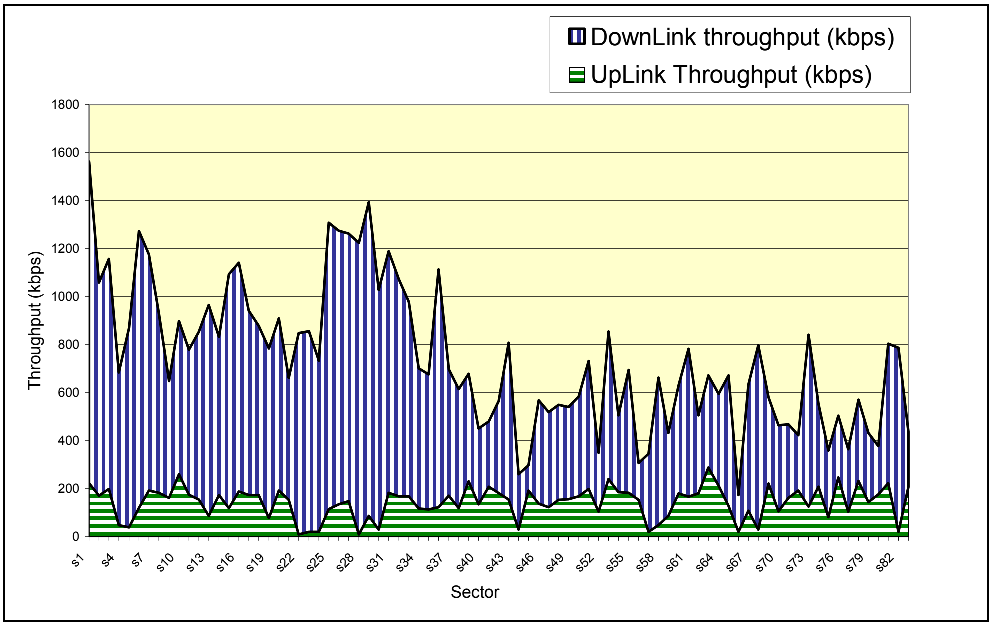

FIGURE 8. DOWNLINK VERSUS UPLINK THROUGHPUT BY SECTOR

Ultimately, Figure 8 presents the distribution of the measured throughputs (uplink and downlink) by sector. Therefore dense urban zone (Nice city downtown) is highly populated with business profile users which are more likely to request the videoconference service. The sectors 25 to 37 show the highest measured throughput which confirms the user profile (business users) distribution and the geographical data (GIS).

Results obtained from the implementation of 1xEV-DO can be summarized as follows:

- The proposed set of models provides a useful approach to include parameters and factor which play a major role in real mobile wireless network system. The user profile, its mobility and the characteristics of its mobile device are basic parameters to evaluate the capabilities of the 1xEV-DO radio access technology.
- Services, such as mobile Internet access, do not require a lot of throughput. Therefore such services demonstrate low values of C/I and E_C/I_0 rates. Whereas others, such as the multimedia message service (MMS) and the videoconferencing, which need the highest throughput, are more dependant of these signal quality rates. High C/I or E_C/I rates can lead to service rejection when the signal quality is not sufficient enough to satisfy the required quality of service;
- The signal quality has a direct impact over the throughput offered by the radio access technology to each mobile user. A realistic coverage area, based on GIS data, was considered in order to verify such results.

5. Conclusion

In this paper we proposed a model-based performance evaluation methodology to assess the capabilities of the 1xEV-DO radio access technology. Our methodology demonstrates promising capabilities to include a wide range of parameters which play a major role in mobile wireless network systems. These parameters include the network characteristics, the user characterization, the user mobility, the terrain topology, and the quality of service constraints.

Our methodology is original for two main reasons. First we use a realistic virtual environment based on a geographic information system (GIS). These geographic data enable a plausible radio signal propagation model. Second, in contrast to conventional analytical evaluation approaches, our methodology includes the user profile as well as the user mobility models. These two models reflect the dynamic of a real mobile wireless network system.

Based on those simulation results, we conclude that 1xEV-DO constitutes a promising choice that guarantees the support of services and advanced applications to be offered in future wireless networks. The future work is oriented towards the evaluation of other performance parameters, such as the transmission delay, the spectral efficiency and the bit error rate.

6. Acknowledgement

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7. Reference

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