Global Approach of Channel Modeling in Mobile Ad Hoc Networks Including Second Order Statistics and System Performances Analysis

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ABSTRACT
Mobile ad hoc networks (MANET) are very difficult to design in terms of scenarios specification and propagation modeling. All these aspects must be taken into account when designing MANET. For cost-effective designing, powerful and accurate simulation tools are needed. Our first contribution in this paper is to provide a global approach process (GAP) in channel modeling combining scenarios and propagation in order to have a better analysis of the physical layer, and finally to improve performances of the whole network. The GAP is implemented in an integrated simulation tool, Ad-SMPro. Moreover, channel statistics, throughput and delay are some key points to be considered when studying a mobile wireless networks. A carefully analysis of mobility effects over second order channel statistics and system performances is made based on our optimized simulation tool, Ad-SMProl. The channel is modeled by large scale fading and small scale fading including Doppler spectrum due to the double mobility of the nodes. Level Cross Rate and Average Duration of Fade are simulated as function of double mobility degree, α defined to be the ratio of the nodes' speeds. These results are compared to the theoretical predictions. We demonstrate that, in mobile ad hoc networks, flat fading channels and frequency-selective fading channels are differently affected. In addition, Bit Error rate is analysed as function of the ratio of the average bit energy to thermal noise density. Other performances (such as throughput, delay and routing traffic) are analysed and conclusions related to the proposed simulation model and the mobility effects are drawn.

Keywords: *Scenarios, channel, mobility, second order statistics, Ad hoc networks, BER, performances.*

1. INTRODUCTION

Many researchers prove that the using of simulation tools is indispensable for better analysis of new technologies especially in the field of Mobile Ad Hoc Networking. The need for reproducible results and the flexibility of analysing the effect of a specific parameter or combination of parameters explain why most published results related to networks performances and new protocols have been achieved using simulators such as OPNET, NS-2 and GloMoSim. But these results are sometime criticized because of the inaccuracy of the simulators especially regarding physical layer modeling [1], [2].

In high dynamic mobile ad hoc networks, the characteristics of channel statistics and the network performances are strongly affected by the variability of the wireless channel. This variability is due to phenomena such as large scale fading, multipaths and Doppler Effect. The specific context of mobile-to-mobile channel increases the effect of channel modeling in mobile ad hoc networks. The effects of physical layer including mobility are intensively investigated particularly in cellular networks [3], [4]. But more investigation of these effects in mobile ad hoc networks is needed although it exist some related publications [2], [5].

The global purpose of this paper is to exploit the knowledge the double mobility effects in ad hoc networks to improve the system reliability and to increase end-to-end performances for effective deployment. Some performance analyses in this article are made with OPNET. But to overcome the lack of accuracy of its default propagation model (free space), an appropriate model is developed with MATLAB and linked to OPNET.

This paper addresses a global approach in channel modeling by combining scenarios specification including mobility models and propagation issues (pathloss, multipath and Doppler). The global approach process (GAP) is carried out in five sequential stages using an integrated platform, Ad-SMPro. All the results in this paper are based on more accurate simulator which is a combination of our simulation tool and OPNET Modeller. This is the concern of section 2 which briefly describes the scenarios generation, the propagation models and the how the link with OPNET is made. Using this optimized tool, the analysis of double mobility effects over channel statistics particularly second order statistics, Level Cross Rate (LCR) and Average Fade of Duration (ADF) is performed in section 3. Section 4 gives BER analysis and some global networks performances (throughput, delay and routing traffic) based on AODV (Ad hoc On Demand Distance Vector) protocol. Lastly, section 5 summarises the keys points and presents the future work.

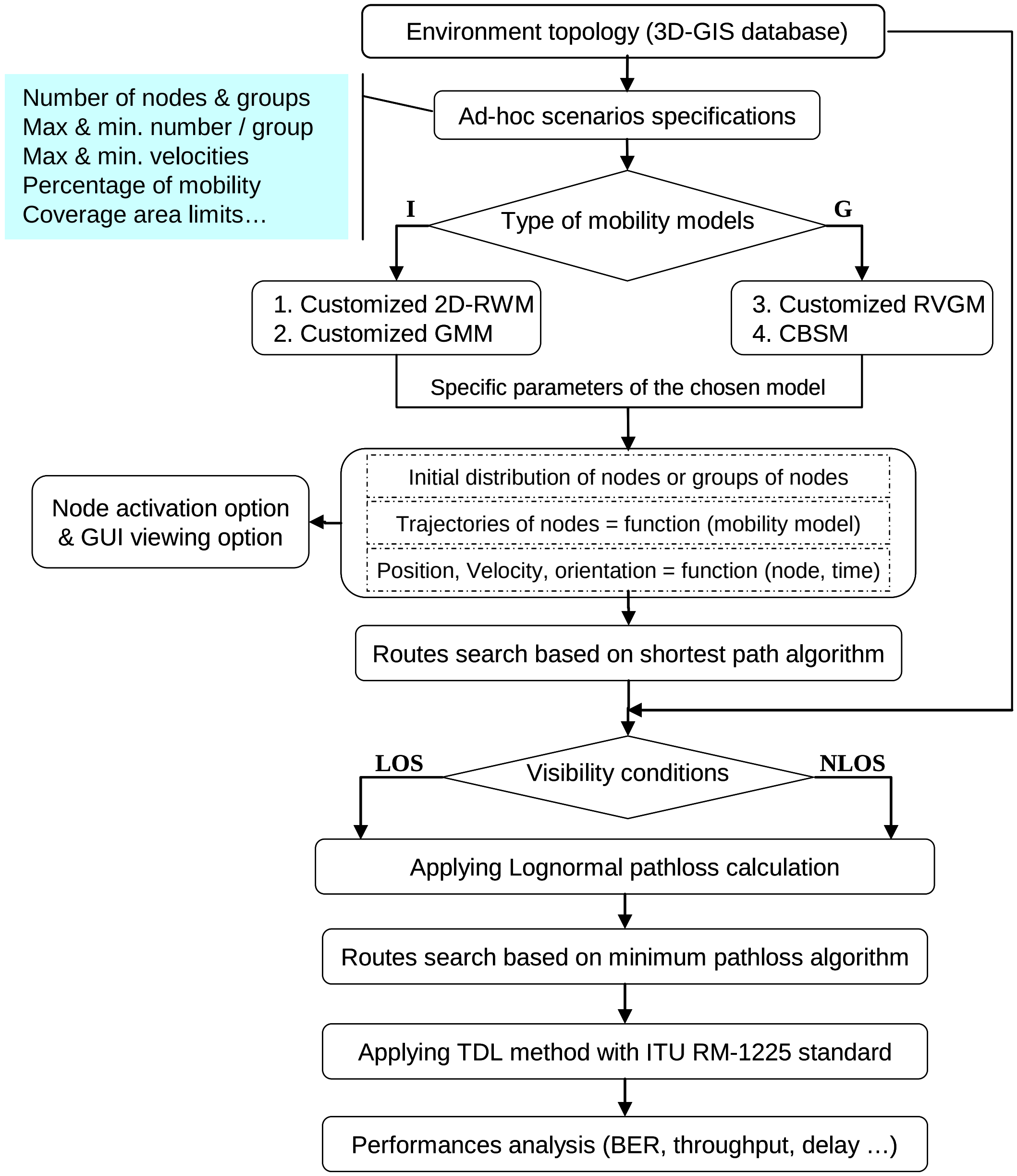

Figure 1: Schematic algorithm of Ad-SMPro platform

2. SCENARIOS AND CHANNEL MODEL FOR SIMULATION

The global approach process (GAP) is a response of all the challenges described in the introduction by gathering scenarios, mobility, propagation (using real environment topology) and performances analysis. As overview of the GAP, this section gives a brief description of what each simulation step is involved to. They are summarized on figure 1. More details on the simulation results for steps 2- 5 are presented below.

Step 1: Environment topology

This step consists to extract environment parameters using Geographic Information System (GIS) data. Using 3D-data will increase the accuracy of the propagation prediction especially in pathloss calculation. These parameters can be also used for scenarios specification.

Step 2: Scenarios generator (mobility pattern)

The usefulness of this step is an automatic generation of scenarios by setting parameters of nodes, coverage area, type of mobility and simulation conditions in the network. The scenario specification is an important stage of the simulation process. It consists for taking into account all needed parameters to define realistic mobility pattern with respect of geographical environment and other behaviours of nodes (such as "on" or "off" state).[6].

Step 3: Large-scale fading model

Based on environment topology, the large-scale fading is computed using various propagation models. The lognormal shadowing (LNS) propagation model is used in this paper. The pathloss is calculated for all found links in the network thanks to graph theory. The LNS pathloss calculation is given by [7]:

$$L_{(dB)} = L_{d_0} + 10n\,log_{10}\left(\frac{d_{i,j}}{d_0}\right) + X_\sigma \qquad \text{(eq. 1)}$$

Where, $L_{(dB)}$ is pathloss between two nodes (in dB), L_{do} is the pathloss at a reference distance d_0, $d_{i,j}$ is link length between the two nodes, n is the pathloss exponent and X_σ is a zero-mean Gaussian random variable with standard deviation σ.

The typical values of n and σ in outdoor shadowing environment are $2.7 \leq n \leq 5$ and $4 \leq \sigma \leq 12$.

One major result in this stage is the comparison between the routes search based on shortest path algorithm and routing based on pathloss. An example of a snapshot of this comparison is shown on the figure 2. The corresponding 3D map showing LOS and NLOS links is depicted on the figure 3.

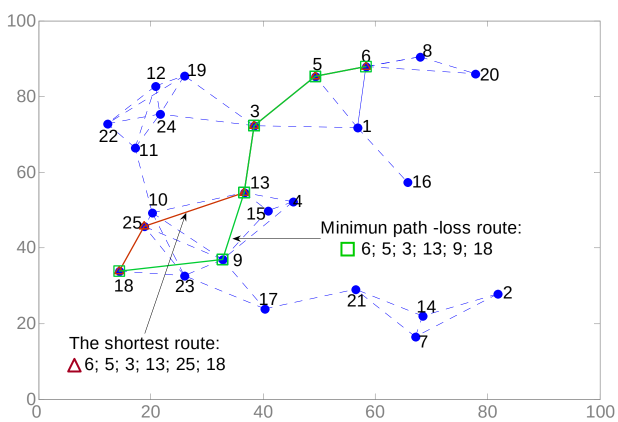

Figure 2: Snapshot at t = 82.5 second: Shortest path vs. Minimum pathloss route

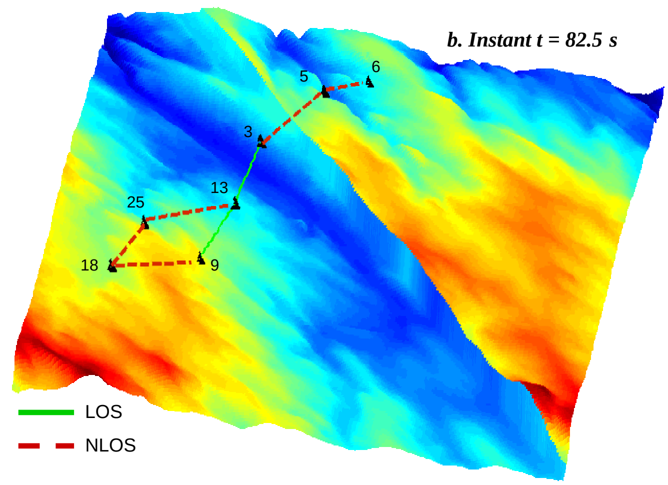

Figure 3: Visibility conditions over each link

Step 4: Small-scale fading model

The two main physical factors which influence small-scale fading are multipath propagation and speed (velocity) of mobile nodes. These factors are combined to compute the channel coefficients and channel statistics (cumulative function, level cross rate and average duration of fade).

The multipaths are modelled as Tapped Delay line (TDL) system with ITU-RM 1225 standard [8], [9]. It specifies 3 types of test environments (vehicular, pedestrian and indoor), but this paper is only focus on vehicular and pedestrian environments. For each test environment, 2 coexisting channels (A and B) are defined to be respectively the low delay spread and the high delay spread case. The occurrence of each channel is defined to be respectively 40 % and 55 % in vehicular and pedestrian environments.

The total maximum Doppler frequency is calculated knowing the speeds of the two nodes as:

$$f_m = f_{m1} + f_{m2} \quad with$$
$$f_{m1} = \frac{v_1}{\lambda}\ and\ f_{m2} = \frac{v_2}{\lambda} \qquad \text{(eq. 2)}$$

Where λ is the wavelength of the signal.

Instead of using the classical Jake's spectrum, a more suitable mobile-to-mobile (M2M) Doppler spectrum is used [10]. Its power spectral density (PSD) is defined as function of the degree of double mobility, $\alpha = min(v_1,v_2)/max(v_1,v_2)$ which is the key parameter of the analysis.

$$S(f) = \frac{1}{\pi^2 f_{\max}\sqrt{\alpha}} K\left[\frac{1+\alpha}{2\sqrt{\alpha}}\sqrt{1-\left(\frac{f}{(1+\alpha)f_{\max}}\right)^2}\right]$$

(eq. 3)

Where K [] is the complete elliptic integral of the first kind and f_{max} max value of the maximum Doppler shift of the 2 mobile nodes, $f_{max} = max\ (f_{m1}, f_{m2})$.

The shape of Doppler spectrum depends of the speeds ratio (degree of double mobility), α (figure 4).

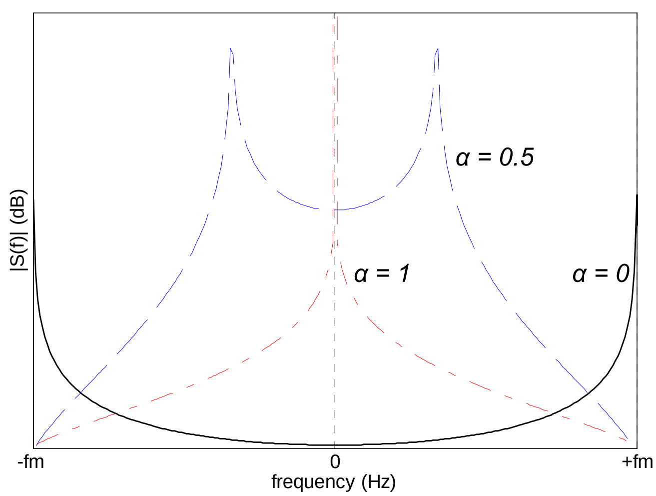

Figure 4: The shape of Doppler spectrum vs. α

The last three steps described above (2 - 4) constitute the core of the GAP. Then, the final step consists of some performances analysis.

Step 5: Performances analysis

The bit error rate (BER) vs. ratio of bit energy to noise (Eb/N0) is discussed by varying the type of channel and Doppler shift. Some global performances are also analyzed. More details are given in section 4.

All models developed in these steps are implemented on a integrated simulation platform, Ad-SMPro simulator for easy and convivial use. The acronym Ad-SMPro means **Ad** hoc networks **–** **S**enarios, **M**obility and **Pro**pagation. Our implementation is made using MATLAB package. Moreover, in order to make suitable comparison with commonly used models in many networks simulators, a combined tool including our simulation platform (Ad-SMPro) and OPNET Modeller is made [11].

The final goal is to take into account these results in the network upper layers design. In fact, the scenarios specification model and propagation models currently available in many simulators are very limited. The table 1 summarized the propagation models available in the latest versions of the three most used networks simulators.

Simulator	***Pathloss models***	***Multipath fading models***
OPNET	Free space	Not included
NS-2	Free space, Two ray	Rayleigh & Ricean
GloMoSim	Free space, Two rays…	Rayleigh & Ricean

Table 1: Propagation models available in OPNET, NS-2 and GloMoSim

Providing a link between the Ad-SMPro platform and other simulators will sidestep the lack of accuracy in their wireless channel modeling. Only the link with OPNET Modeler is provided on our simulation platform.

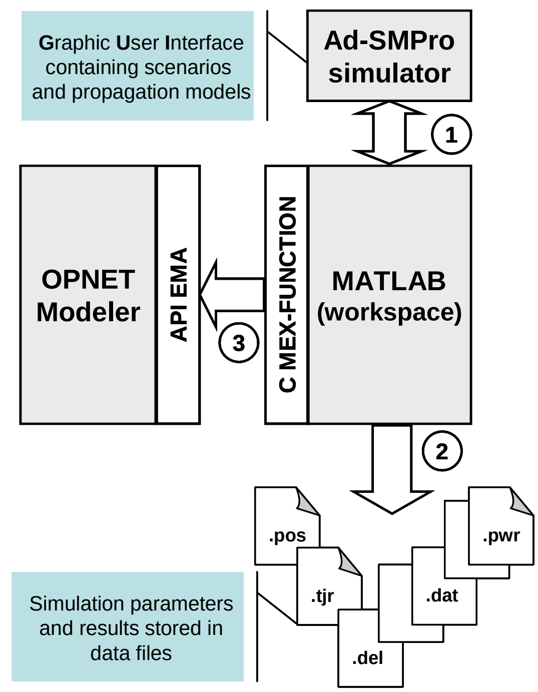

Figure 5: Link process between Ad-SMPro simulator and OPNET Modeler

The link process is summarized on figure 5. Scenarios, pathloss and fading for all nodes in the whole network are computed using the Ad-SMPro platform. The simulation results are saved in MATLAB-workspace or stored in data files (for further use). The link to OPNET Modeler is made using MATLAB C-MEX functions and OPNET EMA (External Model Access).

3. MOBILITY EFFECTS OVER CHANNEL STATISTICS

The statistics are very helpful to interpret the channel behaviour using quantitative values. The second order statistics, level crossing rate (LCR) and average duration of fade (ADF) are derived in [12]. LCR is the rate at which the channel envelope crosses a certain signal level, R in positive going direction and given in [10] by:

$$N_R = \int_0^{\infty} \dot{r} p(R,\dot{r}) d\dot{r} \qquad \text{(eq. 4)}$$

Where the dot indicates the derivative, $p(R,\dot{r})$ is the joint power density function of r and its derivate at $r = R$.

LCR can be written as function of ρ, the ratio of R to its rms value, and μ_2 which is the second moment of the Doppler spectrum $S(f)$.

$$N_\rho = \sqrt{\frac{\mu_2}{\pi\sigma_1^2}} \cdot \rho e^{-\rho^2} \qquad with\ \rho = \frac{R}{\sqrt{2\sigma_1^2}} \qquad \text{(eq. 5)}$$

ADF gives the average duration of fade below the considered level, R as given in [10] by:

$$\bar{\tau} = \frac{1}{N_R} p(r < R) \qquad \text{(eq. 6)}$$

$$\bar{\tau} = \frac{1}{f_{\max} \cdot \sqrt{2\pi(1+\alpha^2)}} \frac{1}{\rho} (e^{\rho^2} - 1) \qquad \text{(eq. 7)}$$

Simulations results based on our simulation model are compare to theoretical predictions according to equations 5 and 7 (figures 6 and 7 corresponding to vehicular environment). The expected results as predicted by theory are confirmed by the simulation for values of double mobility degree less than 1 ($\alpha < 1$). Indeed, simulation and theory show a good agreement for these values even though the pick value of LCR is greater in simulation for $0 < \alpha < 1$.

Globally, in simulation or in theory, the figures 6 and 7 show that LCR increases and ADF decreases with the increasing of α. But for α =1, the simulations are completely different either for LCR or ADF.

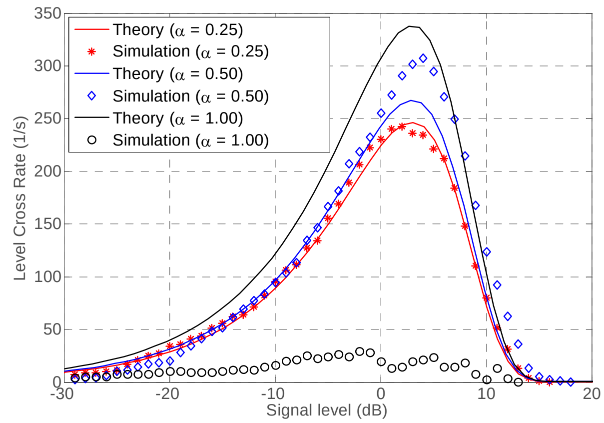

Figure 6: LCR for different values of α

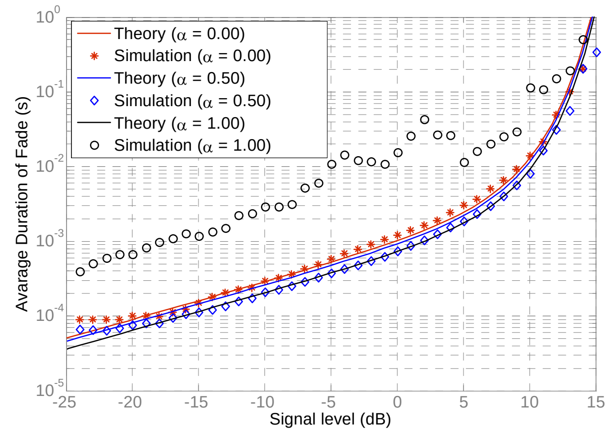

Figure 7: ADF for different values of α

In theory, ADF is expected to increase for α = 1 compared to α < 1 but simulation shows that ADF highly decreased for this value. Assuming that 2 nodes are moving with the same speed and in the same direction, all occurs as if the 2 nodes were fixed and only their physical environment was changed. The mobility effect is annihilated, thus the reduction of the LCR.

Inversely, ADF is increased for the same reason. However in practice, this case (α = 1) occurs seldom if ever.

4. SOME PERFORMANCES ANALYSIS UNDER REALISTIC ENVIRONMENTS

BER analysis

The average bit error rate (BER) is analyzed as a function of the ratio of average bit energy to thermal noise level (Average BER vs. Average E_b/N_0) for different value of α.

In fading channel, the average BER is related to the instantaneous one by:

$$\overline{P}_b(E) = \int_0^\infty P_b(E,\gamma) p_\gamma(\gamma)\, d\gamma \qquad \text{(eq. 8)}$$

Where, $p(*)$ is the power Distribution function (PDF) of the instantaneous signal-to-noise-ratio. The Rayleigh PDF is assumed in the following simulation.

Based on the Doppler spread and by comparison of the coherence time with the signal symbol period, the fading channels can be defined to be slow or fast. Let, considering for our first simulation, a fast flat fading channel. Under this assumption, the fading amplitude is assumed to be constant within the duration of a single symbol period but varies from symbol to symbol. Recall that in flat fading channel, the maximum multipath delay is lower than the symbol period of the signal. For our second simulation, a fast frequency-selective fading channel is considered.

Considering a DQPSK signal transmitted over this fading channel, the corresponding average BER, with differential detection over two symbols observation, is given in [13]:

$$\overline{P}_b = \frac{1}{2}\left[1 - \sqrt{\frac{2(\rho\overline{\gamma}_b)^2}{(2\overline{\gamma}_b+1)^2 - 2(\rho\overline{\gamma}_b)^2}}\right] \qquad \text{(eq. 9)}$$

Where, $\overline{\gamma}_b$ is the average SNR per bit and ρ is the fading correlation coefficient.

For M2M channel, ρ is defined in the case of omnidirectional antennas and isotropic scattering conditions around transmitter and receiver to be:

$$\rho = J_0\left(2\pi f_{m_1} T_s\right) J_0\left(2\pi f_{m_2} T_s\right) \qquad \text{(eq. 10)}$$

Where, J_0 is the zeroth-order Bessel function of first kind and T_s is the symbol duration.

It is important to notice the presence of an error floor (the minimum asymptotic value of the average BER) linked to the correlation value which depends directly to the Doppler spread. Its expression is also given in [13]:

$$\overline{P}_b = \frac{1}{2}\left[1 - \sqrt{\frac{\left(\frac{\rho}{\sqrt{2}}\right)^2}{1-\left(\frac{\rho}{\sqrt{2}}\right)^2}}\right] \qquad \text{(eq. 11)}$$

For the following simulations, complex Gaussian random variables are generated and filtered according to this PSD. An Inverse Fast Fourier Transform (IFFT) is applied to obtain the channel coefficients in time domain sampled according to the Doppler bandwidth. Finally, an over-sampling is performed to have these coefficients at the symbol rate.

The carrier frequency and the symbol rate are respectively fixed at 900*MHz* and 24*Ks/s* (kilo-symbols per second). The average E_b/N_0 takes value between 0 and 80 dB.

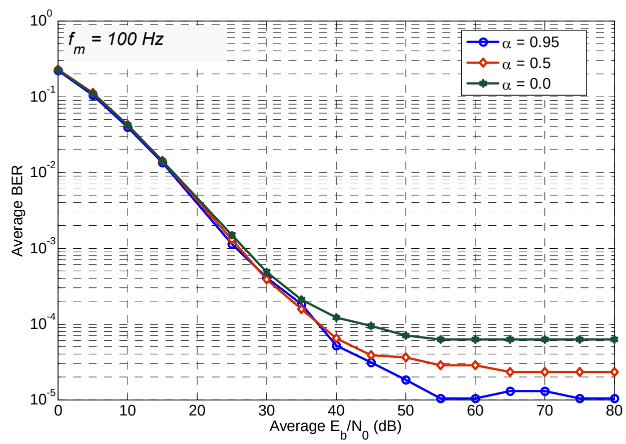

Figure 8: Average BER vs. Average E_b/N_0 for different values of α

The first simulation is carried out for a fixed value of maximum Doppler shift, f_m = 100 Hz. The three curves correspond respectively to equals 0, 0.5, 0.95. The results of the simulations are shown in figure 8. For a given f_m, the difference between the error probabilities for each value is not significant. This result is expected, given that the error floor depends essentially on the $f_m T_s$ value. In fact, for average $E_b/N_0 < 30$ dB, the average BER is almost the same for all values of α. For average $E_b/N_0 >$ 30 dB, the error floor slightly decreases with the increasing of α.

The simulations are made using low delay spread vehicular channel (A) as defined by ITU-R. 1225 [8]. The same results are obtained for high delay spread vehicular channel (B).

The second simulation is carried out for a constant value of $f_m T_s = 5.10^{-3}$. The average E_b/N_0 takes value between 0 and 70 dB.

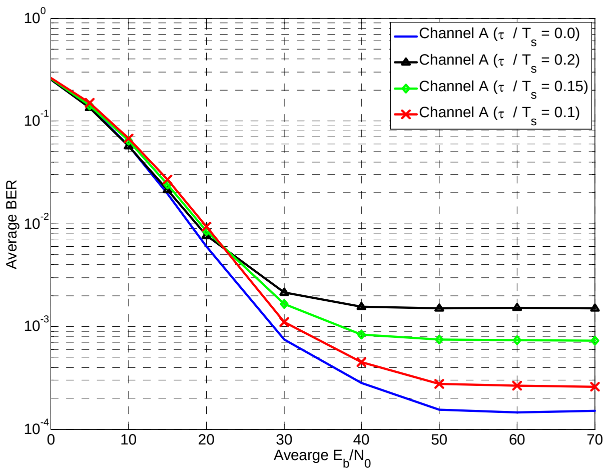

Figure 9: Average BER vs. Average E_b/N_0 for different values of τ/T_s (vehicular A)

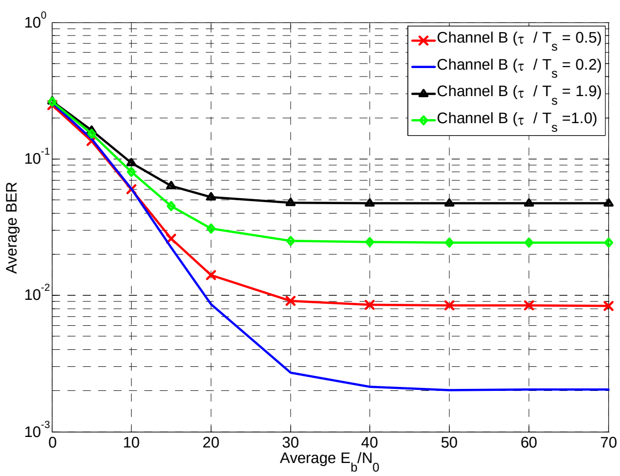

Figure 10: Average BER vs. Average E_b/N_0 for different values of τ/T_s (vehicular B)

The main parameter which affects frequency selective channels is τ/T_S (figures 9 and 10). The BER of both channels A and B decreases when the ratio τ/T_S increases. The effects α is not significant due to fact that inter-symbol interference (not Doppler spread) is mainly responsible of errors in frequency selective channels.

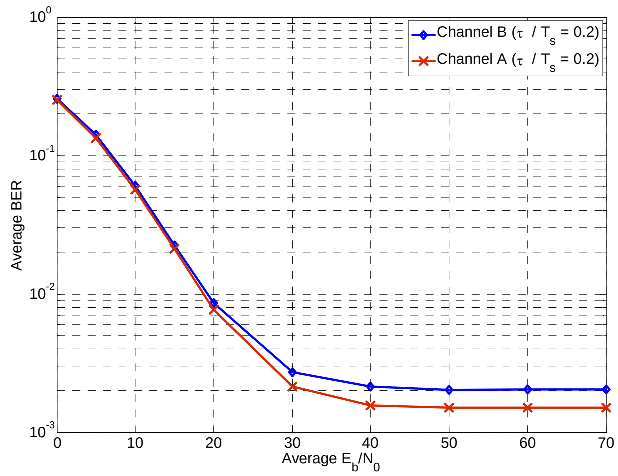

Figure 11: Average BER vs. Average E_b/N_0 for the two channels $(\tau/T_s = 0.2)$

For a given τ/T_S, the average BER floor of the channel B is slightly greater compared to the channel A (figure 11), mainly due to the PDF magnitude difference between the two channels.

Other performances analysis (throughput, delay and routing traffic)

Three simulations are made to quantify respectively the performances in term of throughput, delay and routing traffic. All the nodes can randomly send a different size of data to any destination within the network. The throughput and the delay are related to the global performances of the network and routing traffic is related to AODV protocol. For each simulation, a comparison is made between the results obtained by the combining OPNET with our simulation model (OPNET + Ad-SMPro) and those obtained using OPNET only.

The default channel model used in OPNET and similar tools will lead to the network performances overestimation and the network is undersized accordingly. The network throughput with OPNET only is greater than the one obtained by OPNET and Ad-SMPro combination. In fact, the OPNET propagation default model assumes LOS conditions over all links. This assumption is mistaken on real topology environment which presents either LOS or NLOS links. Taking into account NLOS conditions (as it is made by OPNET + Ad-SMPro) decreases the throughput (figure 12). Inversely, the delay is greater in OPNET + Ad-SMPro compared to OPNET only. As expected, taking into account the environmental parameter based an accurate simulation tool increases the end to end delay (figure 13).

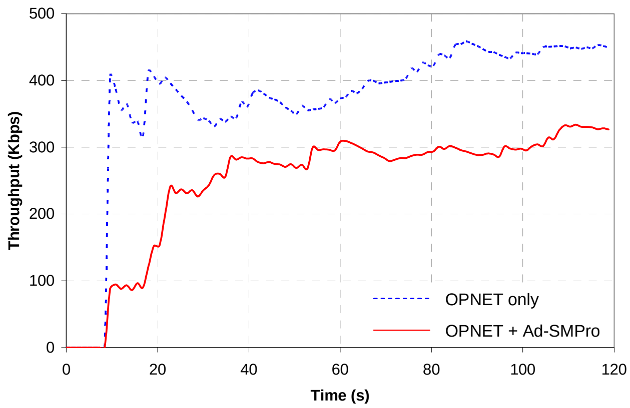

Figure 12: Average throughput in the network

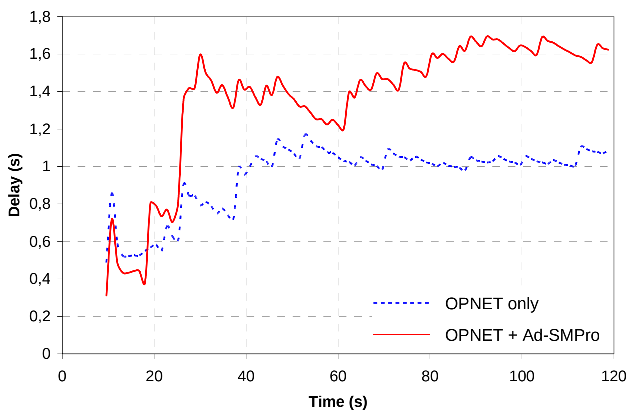

Figure 13: Average delay in the network

The routing traffic represents the amount of routing traffic sent in Kbps in the entire network. The figure 14 shows that the routing control traffic is reduced in OPNET + A case because it based on more accurate parameters of the physical layer. That means, quick route finding and reduction of routing traffic as shown on figure 14.

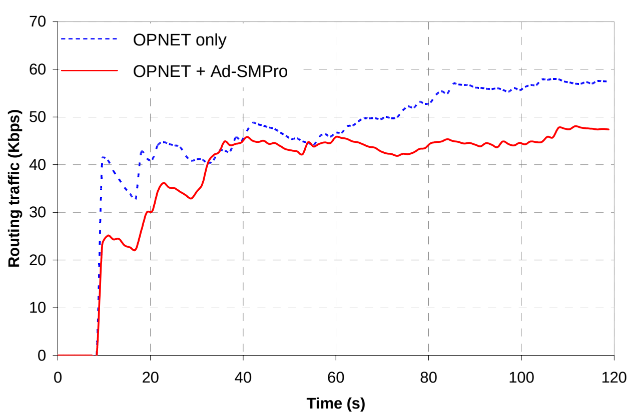

Figure 14: AODV routing traffic sent

5. CONCLUSION AND FUTURE WORK

Mobility effect is a key point when analysing the M2M channel especially in high dynamic mobile ad hoc networks context. How the double mobility affects second order statistics (LCR and ADF) was the first focus of this paper. The performances in terms of BER, throughput, delay and routing traffic are also analysed. Two main conclusions are drawn: The average BER floor is affected by the double mobility degree, α under flat fading channels and the ratio τ/T_s is the main parameter which affects the frequency-selective fading channels. The proposed simulation model leads to more realistic performances and consequently reduces the routing traffic. The on-going work will allows validating the simulation results by experimental test bed.

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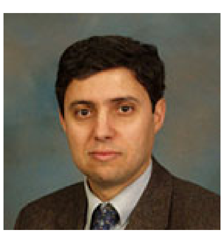

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