DETERMINISTIC CHANNEL CHARACTERIZATION INFLUENCE ON AD-HOC NETWORK ROUTING

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ABSTRACT
The purpose of this paper is to describe an Ad-hoc network platform simulation which uses a deterministic channel characterization. This last one is given by a 3D ray tracing software developed in our laboratory. An Ad-hoc network can be represented by a connectivity graph. Its nodes represent mobile stations and each of its edges is estimated by a cost function which characterizes the quality of radio links. Our study considers two different cost functions for the network routing. The first one is associated to the received narrow band attenuation which takes into account the environment; the second one is the Bit Error Rate (BER) evaluated by a digital transmission chain.
Keywords: Ad-hoc network, Channel characterization, Bit Error Rate, Connectivity graph, Dijkstra algorithm.

1 INTRODUCTION

Nowadays, an increasing interest is devoted to wireless cellular network and particularly to wide-band applications like multimedia services. But these systems operate thanks to centralized supporting structures such as an access point to keep connected each user. These structures limit the adaptability of the network. Indeed, in locations where there is no fixed infrastructure, this last one cannot work. Future generations of wireless network will have to deploy quickly, therefore with a minimum of infrastructure. Ad-hoc networks [1] represent one of these solutions because they work without infrastructure.
In Ad-hoc networks mobile stations are totally autonomous and communicate directly each other. So, each of them operates as a router for the other stations in the network. The path covered by the information may have multiple radio links between the transmitter and the receiver. Mobiles are free to move and roam during a communication with others. Thus, the routing in Ad-hoc networks is quite difficult and a lot of studies are realized to resolve this issue [2] [3].
The aim of this paper is to determine the influence of physical channel characterization in a real environment on Ad-hoc routing, but only for the physical layer of the network.
Firstly, we will present the Ad-hoc Network Simulator (AdNS). This tool developed in our laboratory allows to create and define a complete Ad-hoc network in a particular environment described in 3D. Secondly, we will introduce a ray tracing software [4] and a digital transmission chain, essential for the evaluation of each radio link in this network. Thirdly, we will illustrate the obtained results and more precisely the impact of the deterministic channel characterization in comparison with a statistical one, based on classical normalized channels models provided by the International Telecommunication Union (ITU) [5]. Finally, we will conclude and consider different future works.

2 AD-HOC NETWORK SIMULATOR : AdNS

AdNS allows to simulate a complete Ad-hoc network. The first step consists in the creation of the studied scenario. The second one is associated to the simulation execution and the last one to the analysis of the results.

2.1 Creation of the scenario

First of all, we can choose a real 3D environment. In this area, we define the initial position, route and speed of each mobile. Each trajectory can be cyclic or not and is composed of several points called checkpoints. Mobile's speed can be changed at each checkpoint. **Fig. 1** illustrates a complete scenario with three mobiles (nodes) in a part of the campus of Poitiers's University.

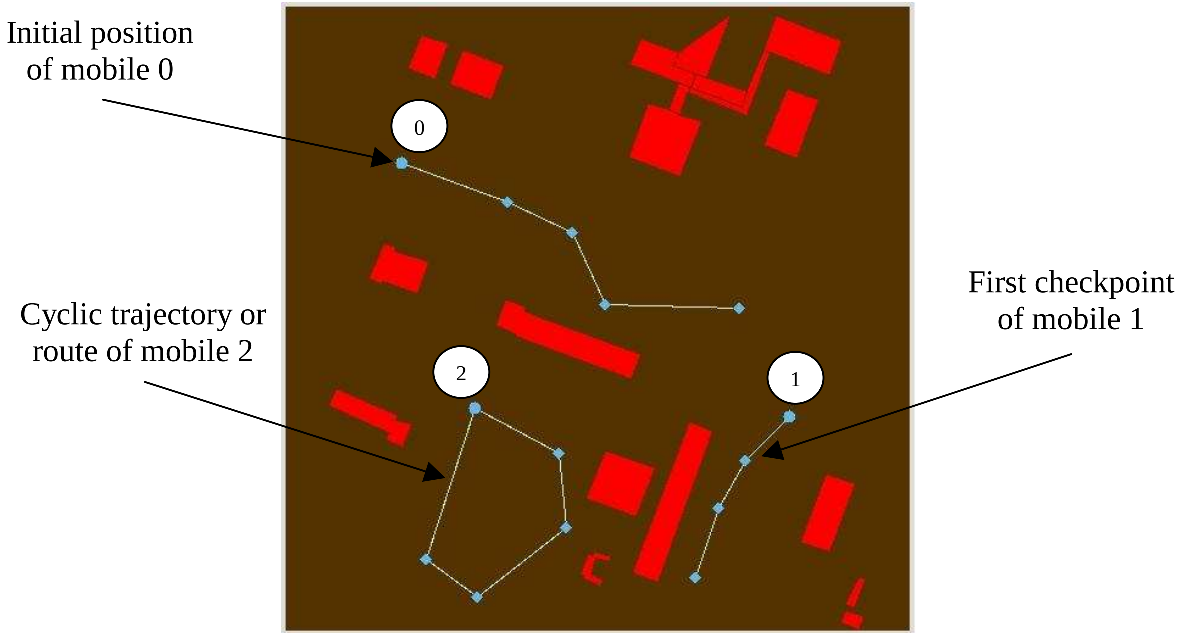


Fig. 1. AdNS interface presenting a scenario composed of three mobiles

Secondly, we define the global parameters necessary for the scenario simulation :

- The sample time representing the elapsed time between two successive iterations during the simulation.
- The number of iterations associated to the scenario simulation.
- The channel characterization represented by a cost function and its necessary parameters used to evaluate each radio link.

Notice : During the different iterations, if one mobile reaches its final checkpoint it stops at this position until the end of the simulation.

2.2 Simulation

During the simulation execution, the simulator evaluates at each iteration :

- The real position mobiles according to their trajectories, speeds and also the sample time.
- The value of each radio link using the cost function previously chosen and detailed in the next section. According to this function, we use different tool and particularly a ray tracing software and/or a digital transmission chain.

At the end of the simulation, results are saved in a file and can be analysed by the studied connectivity graph introduced in the following subsection.

2.3 Results analysis

AdNS creates a connectivity graph corresponding to the scenario. Remember that each node represents a mobile. Moreover, we can choose a transmitter mobile in the network and for each iteration the tool weights each edge thanks to the cost function resulting value which depends on the characterization chosen. At last, the Dijkstra algorithm determines the optimal path between transmitter and a given receiver for each iteration. To illustrate this principle [6], we have considered the simple case described on **Fig. 1,** where each edge is quantified by a random value between 0 and 10. **Fig. 2** illustrates the connectivity graph for one iteration in this example, where nodes 0 and 2 represent respectively the transmitter and receiver.
Notice : The interest of the Dijkstra algorithm is that we can change the receiver node during the analysed results without re-execute a complete simulation. Indeed, this algorithm calculates optimal paths for each potential receiver in the network.

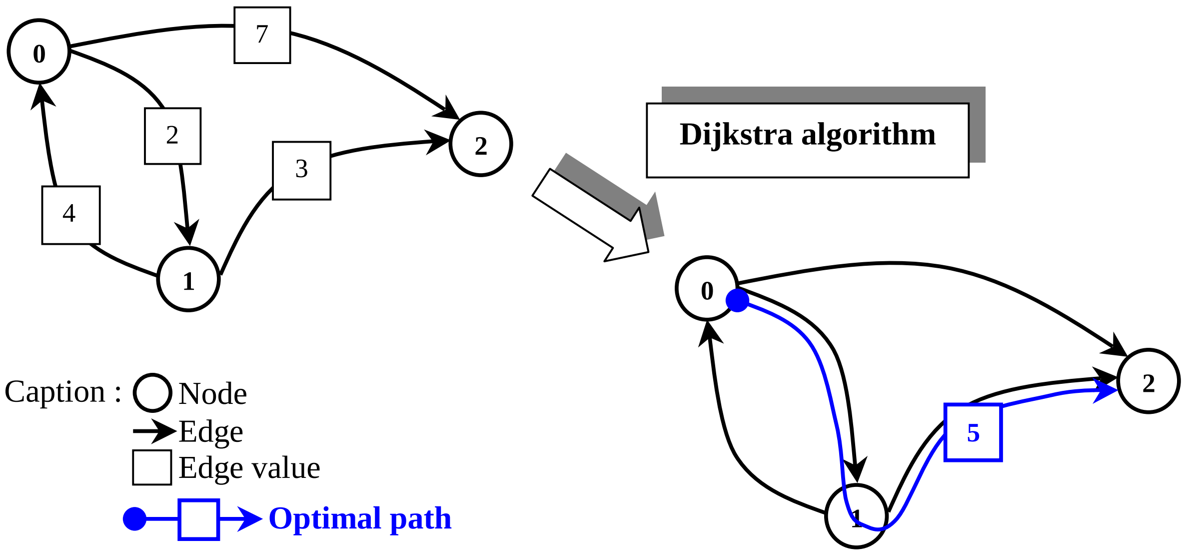


Fig. 2. Connectivity graph of an Ad-hoc network

Consequently, AdNS enables to follow the optimal path evolution at each iteration. **Fig. 3** presents results obtained for two different iterations. We can see the multi-hops aspect of the optimal path (representing in bold on **Fig. 3**) between the transmitter (mobile 0) and the receiver (mobile 2).

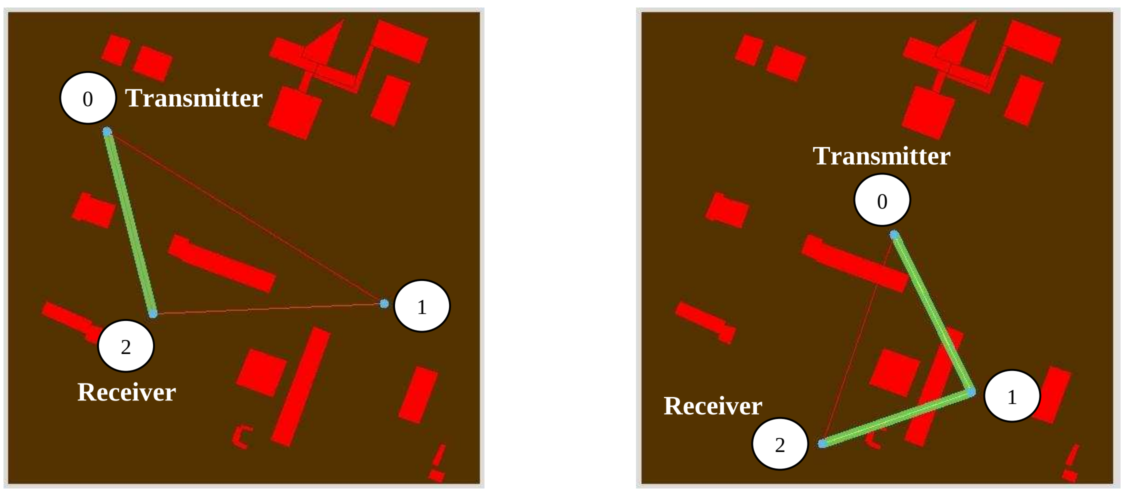


Fig. 3. Final results for two different iterations

3 COMPUTATION OF THE REALISTIC COST FUNCTION

The aim of the cost function is to evaluate the quality of a radio link between each pair of mobiles. Radio links can exist or not according to the network topology. Different characterization, more or less complex, can be used. We use two of them : the first one evaluates the narrow band attenuation using a ray tracing tool, the second one evaluates the BER using this same tool associated to a digital transmission chain based on physical layer of the 802.11b norm (WiFi) [7].

3.1 Ray tracing tool

This propagation tool named Communication Ray Tracing (CRT) combines a ray tracing computing technique and a frequency asymptotic method [8]. It determines not only the narrow band attenuation but the physical impulse response of the channel between two mobiles in the considered environment, as shown the **Fig. 4**. We will work at a carrier frequency equal to 2.4 GHz considered by WiFi Ad-hoc networks.

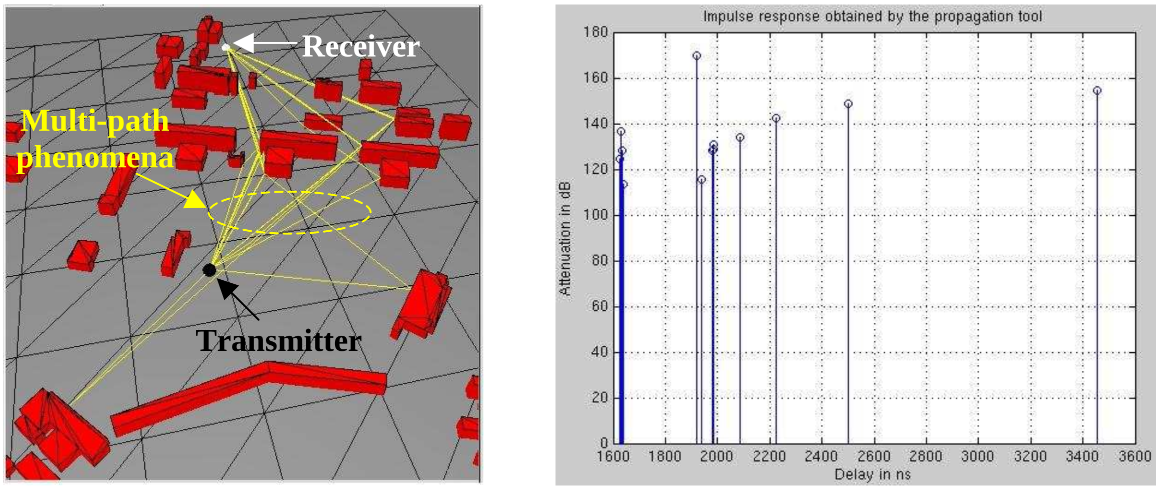


Fig. 4. Propagation Tool and channel impulse response obtained

3.2 The digital transmission chain

The complete transmission chain based on the WiFi 802.11b is presented on **Fig. 5**. The binary signal is generated by a classical bit random source and we can define the number of samples. The modulations used are Binary Phase Shift Keying (BPSK) or Quadrature Phase Shift Keying (QPSK). Then, we spread the modulated signal thanks to a Direct Sequence Spread Spectrum (DSSS). This last one uses a code of 11 chips named Barker sequence and given by the equation (1).

$$\text{Barker sequence : } [\, -1 , 1 , -1 , -1 , 1 , -1 , -1 , -1 , 1 , 1 , 1 \,] \tag{1}$$

The spread signal is more robust to multi-path channel phenomena observed on **Fig. 4**. The chip rate is constant and equal to 11 Mchips/s. In other words, the corresponding bit rate is equal to 1 Mb/s for a BPSK and 2 Mb/s for a QPSK. The channel is simulated by a Tapped Delay Line (TDL) filter with sample time equal to chip time (Tc = 90.9091ns), the inverse of chip rate. This filter uses the channel impulse response calculated by the ray tracing tool. Delays of final sample paths are multiple of the chip time. The noise of the link is added by an Additive White Gaussian Noise (AWGN) to the output of the TDL filter. Its variance n(t) is determined by the Signal to Noise Ratio (SNR) given in dB. At reception, a Rake combiner and a dispreading step are realized before estimating the final binary signal with the demodulation.

Finally, the BER is calculated comparing the initial and final binary signals.

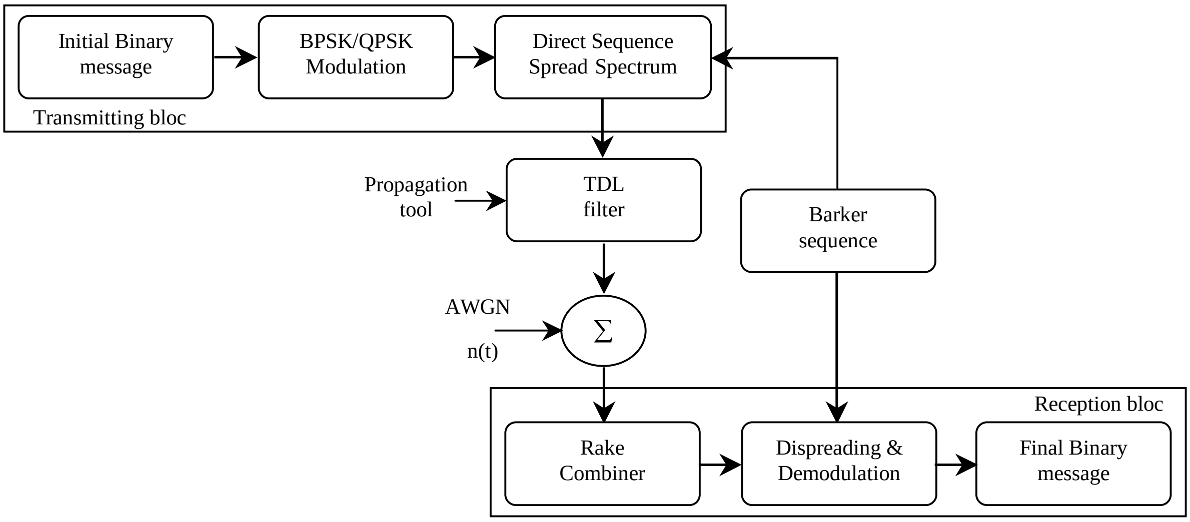


Fig. 5. Digital transmission chain

4 RESULTS AND DISCUSSION

In this section, we study the scenario presented on **Fig. 6**. The chosen environment is the campus of Poitiers's University. There are 5 mobile stations in this one, the first station is static and represents the transmitter. Mobile 3 is the receiver. The stations 1 and 2 are vehicles moving respectively at 8.33 $m.s^{-1}$ and 3 $m.s^{-1}$ (only between its initial position and first checkpoint and then 1 $m.s^{-1}$). Others mobiles are considered as pedestrian with a speed of 1.5 $m.s^{-1}$ or 1 $m.s^{-1}$. We compare results of the optimal paths found for three different cost functions. The first one is associated to the narrow band attenuation. The second one represents the BER estimated by the propagation tool deterministic impulse response. Finally, the last one evaluated the BER associated to the ITU normalized channel models [5]. For the simulation, we consider 8 iterations and a sample time equal to 10 seconds.

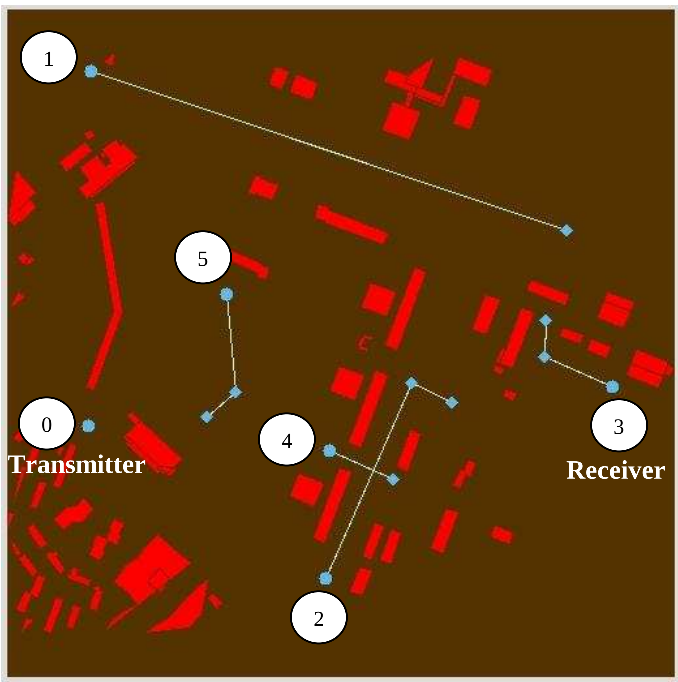


Fig. 6. The studied scenario

4.1 Narrow band attenuation cost function

We define the mobiles' transmitting powers equal to 15 dBm and theirs receiving sensitivities equal to -100 dBm. Thus, we use the propagation tool to determine the narrow band attenuation with a dynamic of 115 dB (15 dBm to -100 dBm). In other words, we consider that the radio link exists only if its attenuation is inferior to 115dB. The result obtained with this cost function is given by the following table (**Table 1**). The final or optimal path is characterized by its cumulated attenuation (ATT).

Iteration	1	2	3	4	5	6	7	8
Time (s)	0	10	20	30	40	50	60	70
Final Path	0-5-3	0-2-3	0-4-3	0-4-3	0-4-3	0-5-2-3	0-1-3	0-5-2-3
ATT (dB)	195.694	192.121	194.377	207.79	205.098	259.76	195.509	315.735

Table 1. Result for the narrow band attenuation cost function

4.2 BER cost functions

We estimate the BER of each existing radio link (global attenuation ≤ 100 dB) thanks to the transmission chain presented in the last section with 10^5 bit samples, BPSK modulation and constant SNR equal to 4 dB. We can use deterministic or normalized impulse responses to define the TDL filter of the channel. Normalized models [5] used are outdoor models corresponding to the studied environment. We consider "Pedestrian" and "Vehicular" profiles when mobiles of the radio link are assimilated respectively to pedestrians (speed ≤ 2.5 $m.s^{-1}$) and vehicles (speed > 2.5 $m.s^{-1}$). We present on the **Table 2** and **3** the two BER cost functions results.

Notice : We use for "Pedestrian" or "Vehicular" profiles the impulse channel response "A" or "B" with a probability respectively equal to 0.45 and 0.55 as defined in [5].

Iteration	1	2	3	4	5	6	7	8
Time (s)	0	10	20	30	40	50	60	70
Final Path	0-4-1-5-3	0-4-2-3	0-4-3	0-4-3	0-5-1-2-3	0-5-2-3	0-1-3	0-5-1-2-3
BER	0.02808	0.03058	0.01624	0.01998	0.0396	0.03154	0.01502	0.02196

Table 2. Results for the deterministic BER cost function (Propagation tool Impulse Response)

Iteration	1	2	3	4	5	6	7	8
Time (s)	0	10	20	30	40	50	60	70
Final Path	0-2-3	0-2-3	0-4-3	0-4-3	0-4-3	0-5-2-3	0-1-3	0-5-2-3
BER	0.02446	0.02662	0.03246	0.03304	0.03292	0.04232	0.02752	0.04774

Table 3. Results for the normalized BER cost function (Normalized Impulse Response)

4.3 Analysis and discussion

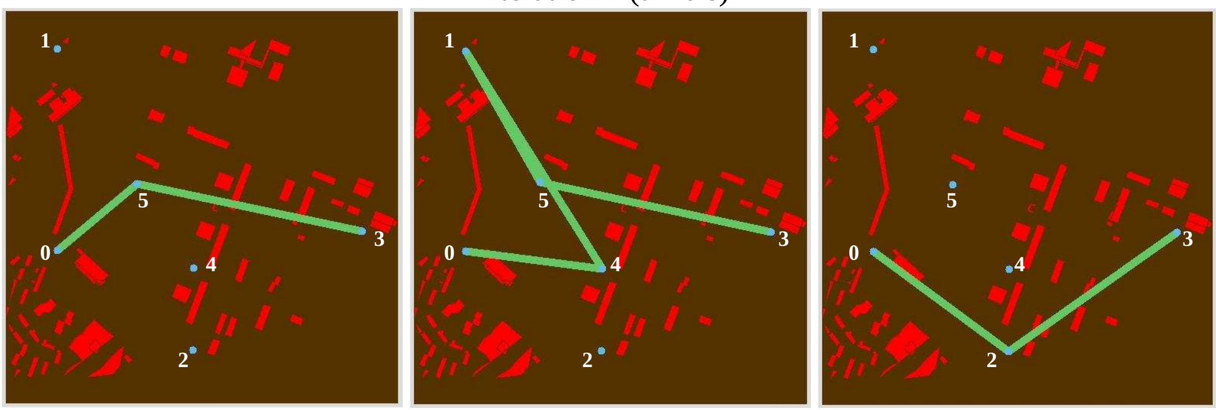
When we compare the optimal path results (**Table 1, 2** and **3**) due to the previous cost functions, we can observe a similar behaviour for 50% of cases. For the other cases, the discrepancy comes from the particularities of each ones :

- Concerning the narrow band attenuation function, we don't take into account the digital transmission chain used. Nevertheless, this last one allows to know if the radio link exists or not between two mobiles for a given dynamic power (transmitting power and receiving sensitivity). To conclude, the narrow band attenuation enables to evaluate each mobile's cover area in the studied environment.

- The BERs corresponding to the Normalized profiles are sensitively constant. These profiles represent an average behaviour of the channel for a specific configuration [5], thus they don't take into account the realistic studied environment. So, the obtained optimal path is minimum in terms of number of hops in the network.
- Finally, the deterministic BER evaluated with the digital transmission chain is directly correlated with the delay spread of the channel impulse response. So, the given optimal path is connected to a minimum cumulated delay spread of radio links. This characterization seems to be more complete than the previous because its considers both the real environment and the used digital transmission chain.

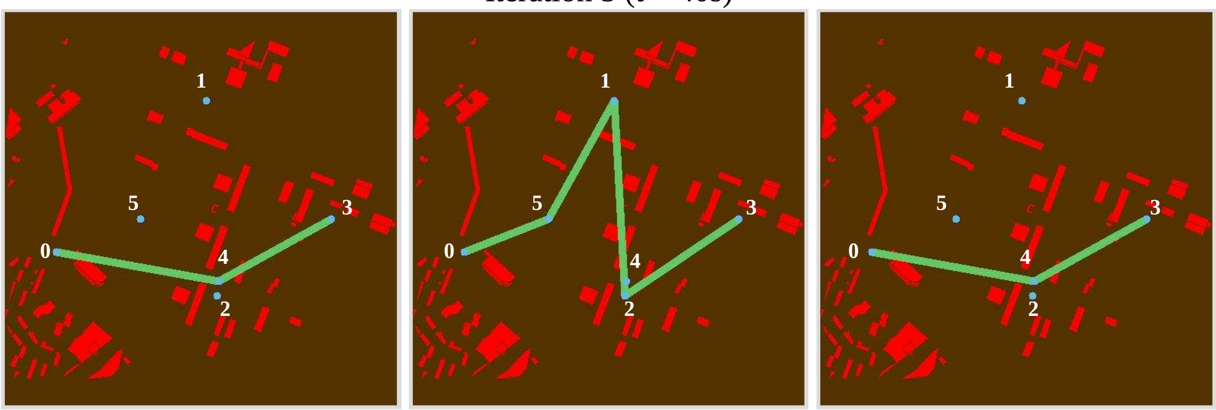
The **Fig. 7** illustrated the routing results obtained for two different iterations of the scenario (iteration 1 and 5) for each considered characterization.

Iteration 1 (t = 0 s)



Narrow band attenuation | Deterministic BER | Normalized BER

Iteration 5 (t = 40s)



Narrow band attenuation | Deterministic BER | Normalized BER

Fig. 7. Comparison of optimal paths obtained for two iterations

CONCLUSION & FUTURE WORKS

In this paper, we have presented an Ad-hoc network simulator which can manage a complete scenario in a real 3D environment. Thanks to the characterization function of the radio link, we can study an Ad-hoc network at different levels.

The described study considers only the physical layer and shows the channel characterization influence on Ad-hoc network routing using a Dijkstra algorithm comparing deterministic with

classical statistical channel model. We have shown that the characterization influence on the routing results for one particular scenario is significant. Although, some complementary studies must be realized in different environments and for several digital systems.
The future works of this study concern firstly the stationary channel's area determination for different environments to obtained a semi-deterministic channel characterization. This last one, should be associated to the implementation of CCK (Complementary Code Keying) [9] modulations in the digital transmission chain to simulate high bit rate (5.5 Mb/s and 11 Mb/s) of the 802.11b physical layer norm.
Secondly, it is important to use real Doppler spectrums based on Bello's works [10] which are connected to the stationary channel's areas.
Finally, we simulate the behaviour of Ad-hoc network routing protocols, like AODV [2] or OLSR [3], in particular environments and compare its efficiencies. For this, we must not consider the network only at the physical layer and realize the implementation of different routing protocols previously enumerate.

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REFERENCES

[1] P. Tortelier, «Les réseaux Ad-hoc» *Assemblée Générale / Séminaire du CNFRS (Comité National Français de Radioélectricité Scientifique)*, January 2003.
[2] C.E. Perkins and E.M. Royer, «Ad-hoc on-demand distance vector routing» *Proc. Second annual IEEE workshop on mobile Computing Systems and applications*, pages 90-100, February 1999.
[3] T. Clausen, P. Jacquet, A. Laouiti, P. Muhlethaler, A. Qayyum and L. Viennot, «Optimized Link State Routing Protocol» *IEEE INMIC*, December 2001. Lums (Pakistan).
[4] F. Escarieu, Y. Pousset, L. Aveneau and R. Vauzelle, «Outdoor and indoor channel characterization with a 3D ray tracing propagation model in urban environment» *IEEE PIMRC*, September 30 – October 3 2004. San Diego (USA).
[5] ITU-R M. 1225, «Guidelines for evaluation radiotransmission technologies for imt-2000» *Technical report*, 1997.
[6] T.H. Cormen, C.E. Leiserson, R.L. Rivest and C. Stein, «Introduction to Algorithms» (Second edition) *MIT Press and McGrawHill*, 2001.
[7] IEEE Std 802.11b-1999, «Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications: Higher-Speed Physical Layer Extension in the 2.4GHz band» (Supplement to ANSI/IEEE Std 802.11, 1999 edition), 1999.
[8] D. McMamara, C. Pistorius and J. Malherbe, «Introduction to the Uniform Geometrical Theory of Diffraction» *Artech House, Inc.* , 1990.
[9] B. Pearson, «Complementary code keying made simple» *Application note*, May 2000.
[10] Y. Chartois, Y. Pousset, and R. Vauzelle, «A spatio-temporal radio channel characterization by a 3D simulation software» *PIMRC, IEEE Personal Indoor and Mobile Radio Communications*, October 2004. Barcelona (Spain).