Impact of the physical layer on the performance of indoor wireless networks

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***Abstract*—In most studies on mobile ad-hoc networks (MANET) simulation models are used for the evaluation of devices and protocols. Such simulations focus on the higher-layer protocols that are analyzed, and suppose that the other layers of the OSI model, particularly the physical layer models, do not interfer with the experimentation. In this paper, we present an innovative implementation of the physical layer for the NS-2 network simulator targeted at the performance analysis of indoor ad-hoc networks. It includes realistic signal reception, interference and noise computation, and effects of people moving indoor. However, as shown in this paper, neglecting the physical layer while modeling wireless indoor environments is error prone and should be considered more carefully.**

I. INTRODUCTION

Simulation is commonly used for the evaluation of wireless network protocols and devices under specific conditions, as the complexity of recent protocols and devices makes it often impossible to analyze them on basis of mathematical and analytical models. However it is often the case that only the specific protocol and all aspects related to the particular study of the protocol OSI layer are simulated in detail, and the effect of interactions with other layers are not accounted for sufficiently. A very common hypothesis is that the lower layers are doing their job well and they have little or nothing to do with the efficiency of the protocol studied. In fact, this may introduce substantial inaccuracies in the model predictions, particularly for wireless protocols where it can even be error prone. In Mobile Ad-Hoc Networks (MANET), most of the recent performance studies consider the effects of multiple layer interactions, but in fact they only limit their consideration to the layer that directly interacts with the protocol being evaluated, either the upper or the lower layer. For instance, many studies on the ad-hoc routing protocols consider the effects of outgoing queues and MAC protocol overheads, but few studies account for the physical layer characteristics such as interference, noise immunity, propagation conditions, and the surrounding physical environment. Many authors neglect their impact in the study of routing protocols, sometimes leading to incomplete conclusions. Our work compares the efficiency of such protocols for various indoor deployment scenarios and addresses the issue of multiple layer interactions in presence of different physical propagation models used at the physical layer. A ray-tracing tool, developed and integrated in the NS-2 network simulator is presented and the impact of level of detail of physical layer is analyzed.

II. FADING AND PATH-LOSS MODELS

Radio propagation models used in the field of wireless networks simulation, and moreover in the study of new routing algorithms are limited to fading, path loss and shadowing with or without additive white Gaussian noise.

Fading is a variation of signal power at receivers caused by the node mobility or environmental changes that create varying propagation conditions from transmitters [10] [9]. Fading models seen in MANET environments present Rayleigh or Ricean distributions, depending on the geometrical conditions. The fading with the Rayleigh distribution is used for mobiles with no line of sight between the emitter and the receiver. The Ricean distribution accounts where it exists a line of sight between nodes. The signal level from the Ricean path with respect to the power from Rayleigh paths can be controlled by a parameter called *Ricean K factor*. The additive white Gaussian noise (AWGN) model is used to model an idealistic channel condition where no signal fading occurs.

Finally, another important model for signal propagation is the path loss, which defines the average signal power loss along a given path on a particular environment. The two-ray path-loss model is suited for line of sight microcell in urban environments, where reflections against scatterers are important. The free-space model is used as a basic reference model. In this model, even nodes far from the transmitter can receive packets, which can result in fewer hops to reach the final destination in MANETs. Therefore, simulation results with the free-space path-loss model is not advisable because it tends to be unrealistic and the signal propagation, even of little power level, may participate in interference far away from the transmitter.

III. RAY-TRACING TOOL

In order to evaluate the influence of physical propagation over the performance of some MANET routing algorithms, we have designed and implemented a new physical layer for the NS-2 network simulator. The NS-2 simulator [12] is a discrete event simulator developed by researchers at UC Berkeley, LBL, USC/ISI, and Xerox PARC. It was first aimed at the design and the analysis of wired networks and transmission control protocols, such as TCP/IP over Ethernet networks, but since that time, extensions [11] have been added to support most of ad-hoc wireless routing protocols as the well-known standard 802.11b [4] [5]. The simulator itself is written in C++ and is open-source. It is possible to add his own extensions and to further develop the software: adding a new functionality can be simply achieved by implementing a subclass of an existing one and overriding the methods implemented by the ancestor class.

The tool we have developed and integrated with NS-2 is made of two parts: a numerical routine and a visual editor. The numerical routine computes the power received on a given point of space by using a *raytracing* technique [13]: starting from the receiver, rays are thrown along every paths that include 1, 2 or 3 reflections and/or refractions or diffraction to the receiver. Any time a reflection,a refraction or a diffraction occurs, the electromagnetic laws are applied in order to determine the resulting field. This routine gives also information on spreading delay, voltage level and field components.

In order to create geometries that will be computed by the raytracing routine, a visual editor has been implemented using the JAVA platform. It allows to model and represent walls and floors as well as elements from a standard library that includes desktop furnitures, office configurations, doors, etc. A display of the field distribution is also available. This editor is presented on Figure 1. and visual output due to an emitter placed in upper left corner of the geometry is presented on Figure 2.

Finally, the editor can export geometry files to a format that can be used later by the numerical routine, while working in the NS-2.

IV. SIMULATION PARAMETERS

Indoor simulation parameters have been chosen to represent an indoor office situation where people evolve in a pervasive computing environment.

The levels are made of $16m^2$ offices and large corridor, for a total floor surface of 50 meters by 50 meters. The velocity of the mobiles is equally distributed between $0.7m/s$ and $1.3m/s$. Mobiles are moving around using random

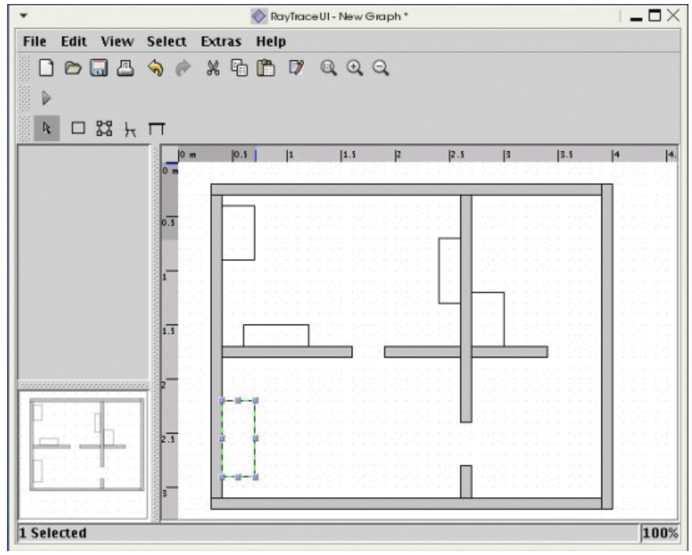

Fig. 1. The JAVA editor front-end

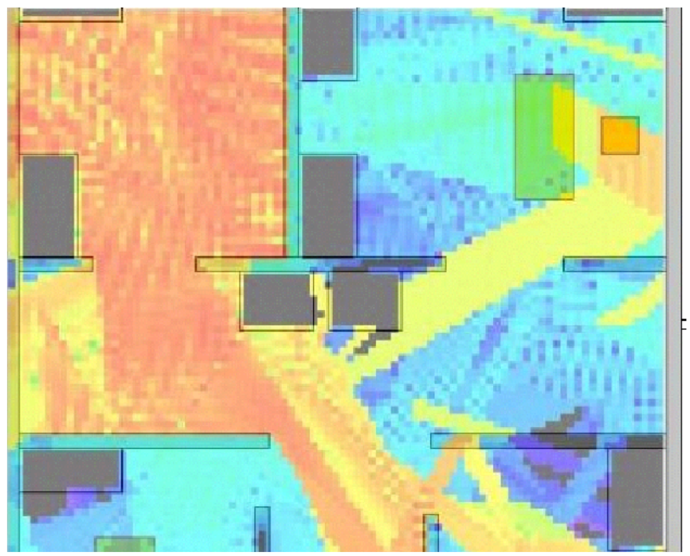

Fig. 2. Field resulting of emitter located on (1m,1m)

waypoint model ; i.e, at starting time, a target point and a speed are chosen and the mobile moves toward its goal. When reached, a new destination and speed are chosen, and so on until the simulation ends.

The raytracing algorithm has been compared to the shadowing prediction model implemented in NS-2. In this instance, the path-loss n-factor is chosen equal to 3.7 and a standard deviation of 2.0. These values are commonly used to represent indoor environments. The emitter power is fixed to 281.8mW (24.5dBm) and reflects the value that are commonly used for wireless PCMCIA cards.

Data transfers are made using 512-bytes UDP packets, in order to avoid to deal with transmission control that would lead to more complex analysis of the results. Finally, common MANET routing algorithms such as AODV [7], DSDV [8] and DSR [6] have been studied.

V. SIGNAL STRENGTH AND MAC THROUGHPUT

During the simulations, the signal strength computed using the physical laws and the shadowing model have been traced in a file. While raytracing model is not itself infinitely accurate, significant differences appear showing that the path-loss model largely overestimates the signal level.

These considerations directly affects the MAC throughput. As an example, Figure 4. shows the MAC throughput for two mobiles having sustained communication and continuously moving away each from other in the office environment described above. One can easily see that with shadowing the communication gives good rates along the whole path while with our model, the level is quite poor and throughput is badly affected.

For 99.3% of the samples, the shadowing values are 10% higher. As it is also the error level that is commonly admitted for the raytracing tool, we can only say here that this tool gives at least the same minimal values as the shadowing. For 90% of the values the error is aqual or more than 100%, meaning that most of the values are the double of the real ones. Finally, about 83% of the samples we have collected reveal to have more than 1000% error.

It is important to note that 10dB (1000%) is the threshold value for SNR in 802.11b systems [3] as in the simulator: if SNR is less than this value, it is considered that no transmission can take place. For instance, let us imagine that a strong noise is present at a given level, say -40dBm, and that the raytracing routine gives us a signal strength of -35dBm for that point. In that case the link will be considered to be broken but we have a probability of 80% that the shadowing model will return a value that is greater than -25dBm, yielding the receiver to establish communication and leading to a simulation error.

VI. AD-HOC ROUTING FOR WIRELESS NETWORKS

There are three categories of MANET routing protocols and algorithms: proactive, reactive and hybrid. Proactive, or table-driven, protocols attempt to maintain consistent, up-to-date information for all destinations on each node. Examples of proactive protocols include DSDV (Destination Sequenced Distance Vector Routing). Reactive, also called on-demand, protocols attempt to minimize overhead by discovering routes on demand and storing route information for only those destinations required by a source node. We study here more closely two reactive

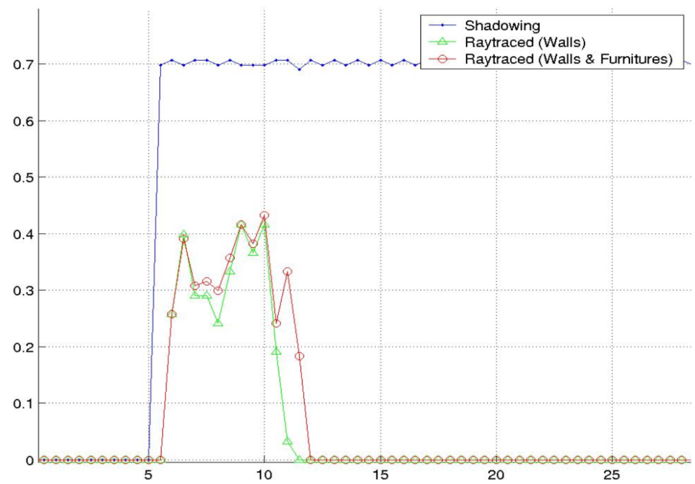

Fig. 3. MAC throughput. Emitter located on (1m,1m), receiver moves away to (30m,30m) with 1m/s speed. Communication starts at t=5s.

protocols known as AODV (Ad hoc On Demand Distance Vector) and DSR (Dynamic Source Routing). Lastly, hybrid protocols combine aspects of proactive and reactive protocols. Hybrid protocols include ZRP [15].

In proactive protocols, each node stores routing information about every other (known) node in the network. These protocols are similar to traditional routing protocols in that they periodically distribute route information to keep all nodes up to date. Each router maintains a table (or tables) to determine the next hop for a packet, given its destination address. The main difference between proactive protocols for ad-hoc networks and traditional implementations is that the former assumes all nodes will participate as routers on the network.

When nodes receive new link cost information, they update their view of the network topology and apply a shortest-path algorithm to choose its next hop for each destination.

On the other hand, reactive protocols require no periodic messaging between nodes. Nodes utilize some form of flood-search mechanism to discover unknown routes only when they need them. The specific mechanisms for flood-searches, route caching, calculating the cost of links and neighbour discovery vary between protocols.

Finally, hybrid routing is designed to provide a balance between proactive and reactive routing approaches. A zone is a local region designed by a single parameter called the zone radius, which is measured in hops. Nodes proactively maintain routing information zones and reactively discover routes for nodes outside their zones.

VII. IMPACT ON PERFORMANCE OF AD-HOC ROUTING ALGORITHMS

Simulations have been also conducted to evaluate the impact of the physical layer model over the performance of routing algorithms. In addition, we have investigated the effects of mobile geometries. While most authors present results related to the influence of mobiles velocity [14], since we are in a building environment, which limits the range of speed available, we rather have focused on the density of nodes. Indeed, one could think that raising the number of nodes in a propagation-aggressive situation can only lead to a more secure routing and better traffic. The simulation below shows node density ranging from 5 nodes (people moving around with hand-held computers) to 60 nodes (hotspot with many information services and users using massively ad-hoc technologies in their computer, phones, etc.). The parameters analyzed are the end-to-end delay (in seconds), the packet delivery fraction (PDF) and the routing overhead which, is defined as the number of packets consumed for routing standardized with the number of packets successfully delivered.

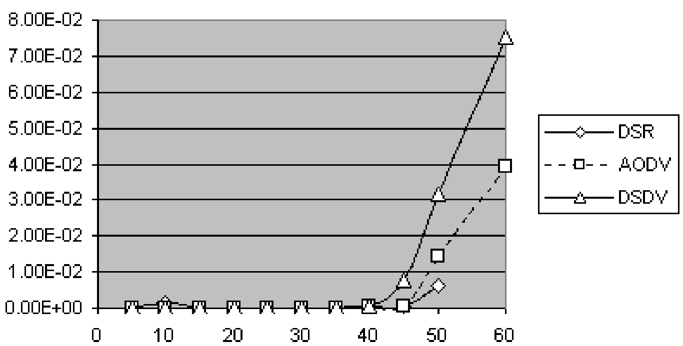

Fig. 4. End to end delay vs. the number of nodes on office floor (shadowing).

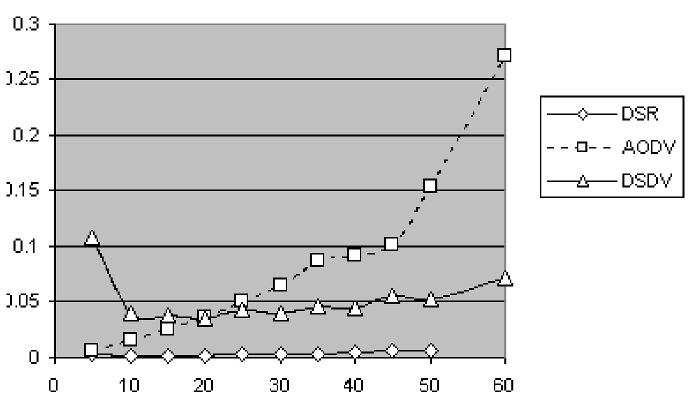

Fig. 5. Routing load vs. the number of nodes (shadowing).

Figures 4 and 5 present the results obtained with the shadowing model while simulation results with the ray-tracing approach are presented in Figures 6,7 and 8. With the shadowing model nearly all of the packets were successfully carried (> 99%) and the protocols behave good, having low delay and showing reasonable routing load. It is important to note that at higher node density, DSDV and AODV are suddenly raising the charge of the network. This conclusion also appears in the raytraced model, when showing unfavorable transmission conditions.

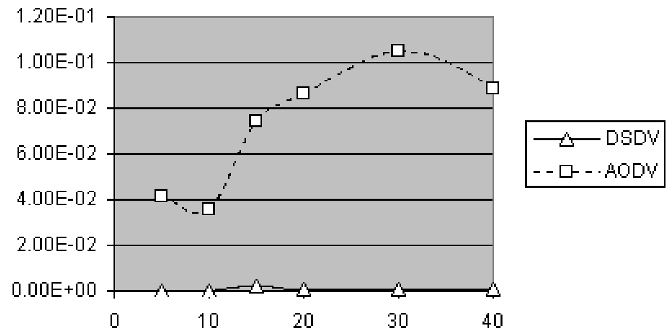

Fig. 6. End to end delay vs. the number of nodes on office's floor (raytracing).

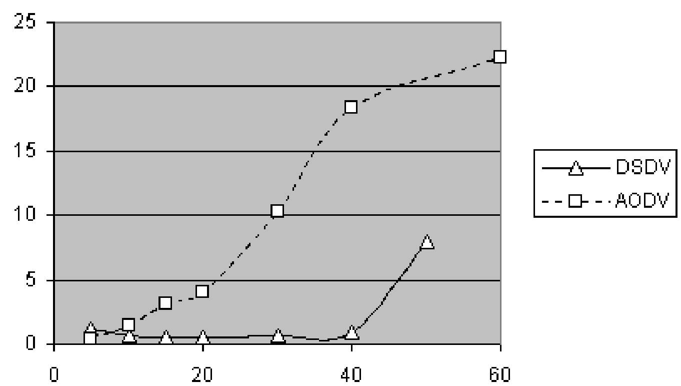

Fig. 7. Routing load vs. the number of nodes (raytracing).

It can be explained by the fact that, in presence of many nodes, link failures occur more often and more information is to be spread over the network. Since DSDV uses a proactive approach (i.e, routes are discovered continuously by broadcasting messages), the delay grows due to the amount of information each node has to receive to ensure routing. AODV uses an on-demand approach (i.e, routes are established when needed) but link failures trigger new route discoveries since it has only one route per destination in its routing table. Thus, the frequency of route discoveries is directly proportional to the number of route breaks, and can lead to large amount of routing information exchanged by the nodes in the time of reconstruction of the transmission paths. This does not occur in DSR, which has cached routes in each node: route discovery in DSR is delayed until all cached routes are outdated.

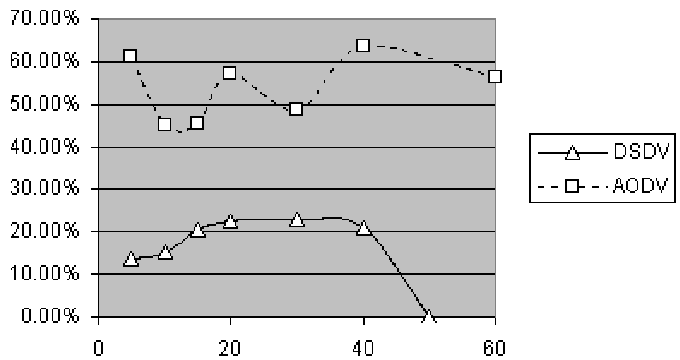

Fig. 8. PDF vs. the number of nodes (raytracing).

Finally, in poor propagation conditions, differences appear in the PDF achieved by the routing algorithms. Once again, this can be analyzed in the light of caching and updating strategies. Indeed, reactive routing algorithms completely or partially rebuild the routes when transmission takes place, while DSDV relies on existing routes that are rebuild periodically. This leads to more inaccurate routes in tables because they are still not updated to reflect topology changes. AODV enforces thus routes coherence but on the other hand it raises slightly the delay and generates heavy routing traffic load.

VIII. Conclusions and Future Work

Computation of interference and noise at each receiver is a critical factor in wireless communication modeling. Most of the actual ad-hoc routing algorithms are studied on the basis of poorly-detailed physical layers while their characteristics, limitations and advantages are tightly bounded to the quality of the lower layers modeling.

In this paper we have shown that equations commonly used to compute signal level, such as path loss, are inaccurate in indoor environments and can even become error prone when studying immunity to noise of mobile ad-hoc networks. The routines we have developed show large performance differences for routing algorithms that are studied in literature. Their behavior does not only seem to degrade gracefully with the propagation conditions but they also present different limitation values (such as maximum node density) and behaviour.

Future work include an implmentation of BER (bit error rate) and/or FER (frame error rate) in the physical layer in order to reflect the sensitivity to noise. Indeed, in NS-2, any signal having less than 10dB of SNR is considered lost, while the importance of BER has been previously discussed and established [1].

Finally, current developments are undertaken to replace the 802.11 layer used in this study and to conduct experiments an simulations over future OFDM systems.

References

[1] Heidemann, Bulusu, Elson, Intanagonwiwat,Lan,Xu,Ye,Estrin and Govindan. Effects of detail on wireless network simulation In...

[2] Additions to the NS network simulator to handle Ricean and Rayleigh fading, http://www.ece.cmu.edu/wireless/.

[3] IEEE Standard 802.3, Part 3: Carrier Sense Multiple Access with Collision Detection (CSMA/CD), Access Method and Physical Layer Specifications, 2000 Edition.

[4] IEEE Standard 802.11b-1999 (Supplement to ANSI/IEEE Standard 802.11, 1999 Edition).

[5] International Standard ISO/IEC 8802-11: 1999(E), ANSI/IEEE Standard 802.11, 1999 Edition.

[6] Johnson, D. and Maltz, D., Dynamic Source Routing in Ad Hoc Wireless Networks, Mobile Computing, Chapter 5, Kluwer Academic Publishers, 1996.

[7] Perkins, C. E. and Royer, E. M., Ad hoc On-Demand Distance Vector Routing, In proceedings of the 2nd IEEE Workshop on Mobile Computing Systems and Applications, pp. 90-100, February 1999.

[8] Perkins, C. E. and Bhagwat, P., Highly Dynamic Destination-Sequenced Distance-Vector Routing (DSDV) for Mobile Computers, In proceedings of ACM SIGCOMM 94, pp. 234-244, August 1994.

[9] Rappaport, T. S., Wireless Communications: Principles & Practice, Prentice Hall, 1995.

[10] Saunders, S. R., Antennas and Propagation for Wireless Communication Systems, Wiley John & Sons, Inc., June 1999.

[11] Wireless and Mobility Extensions to ns-2, http://www.monarch.cs.cmu.edu/cmu-ns.html.

[12] The NS-2 network simulator, http://www.isi.edu/nsnam/ns/index.html.

[13] by Yang, Wu, and Ko, A Ray-Tracing Method for Modeling Indoor Wave Propagation and Penetration. IEEE Transactions on Antennas and Propagation, June 1998.

[14] J. Broch, D. A. Maltz, D. B. Johnson, Y. C. Hu, and J. Jetcheva. A Performance Comparison of Multi-Hop Wireless Ad Hoc Network Routing Protocols. In Proc. of the ACM/IEEE MobiCom, October 1998

[15] M. Pearlman and Z. Haas. The zone routing protocol (zrp) for ad hoc networks. IETF Draft, 56 pages, http://search.ietf.org/internet-drafts/draft-ietf-manet-zone-zrp-02.txt, 1999.