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Extension of WLAN simulator

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I. INTRODUCTION

This document describes the work related to the development of physical extension of WLANSim that has managed in the UdR of Trento in the year 2006 under the TWELVE Project.

The WLANSim was developed by Ilenia Tinnirello and Giuseppe Bianchi and was used to evaluate 802.11 MAC level performance for wireless ad-hoc networks. The evolution of this tool is intended on one hand to use the same framework to evaluate performance for infrastructured networks and on the other hand to introduce channel and propagation features.

So, the goals are the extension of features of simulator with preservation of its structure, and the introduction of a framework that is able to contemplate the use of directional and smart antenna both in mobile devices and in the access points that manage infrastructured networks.

II. SIMULATION TOOLS

In literature there are a lot of Simulators to evaluate system performances for wireless networks. In this section we show a short overview about network simulators and then we describe more in depth the WLANSim tool we use.

Usually network simulators can be divided in category considering how they manage the evolution of the network:

Fluid: the simulator controls the flow of the packets at high level. It considers the packets as a continuous flow and only the changes of the flow intensity are manged by the simulator. On one hand the simulator requires an in depth analysis of the mathematical model and on the other hand the management of interactions among flows can be critical;

Packet-driven: the simulator changes its state accordingly to the packet that is sent. Each sent packet generates a new event that is managed by the simulator, so a real behavior of a network can be simulated. The collision and errors during the transmission must be considered as peculiarity of sent packets;

Time-driven: the simulator evaluates the network performance only in pre-defined instants and esteems network parameters accordingly to the differences among present network status and that is evaluated in previous analysis step;

Event-driven: the simulator is managed by the events that occur in the network. The event can be sending and receiving of the packets, transmissions, collisions, transmission errors and all the event that can be in networks.

A. Literature tools

In this section we shows the most used network simulator that can be found in literature. The following descriptions are high level ones: for more in depth knowledges of each simulator you can refer to author documentations.

1) OPNET: OPNET (*Optimized Network Engineering Tool*) [25] is a commercial tool developed by MIL3Inc that models and simulates communication networks, devices and protocols. The simulator is developed with hierarchical structure where each level is defined by a state machine and is implemented using a like-C language, called Proto-C.

2) GloMoSim: GloMoSim (*Global Mobile Information System Simulation Library*) [27] is developed in UCLA Computing Laboratory and can be used to analyze wide networks, even with more that 1 million of nodes. It is intended for both wireless and wired network and it is developed using PARSEC language.

3) QualNet: QualNet [28] is the commercial version of GloMoSim and has more features than free version. It keeps the same developing philosophy.

4) OMNeT++: OMNeT++ [26] is an open-source project and it is developed in C++ with a friendly user GUI interface. It can be used to simulate traffic model in telecommunication networks, protocols, queuing network, multi-processor model, and other hardware devices.

5) NS-2: NS-2 (*Network Simulator 2*) [24] is one of the most used simulator in scientific community and allows a detailed description of the whole protocol stack. The simulator is event-driven and it is developed using both C++ and OTcl languages. C++ is used to provide efficient simulation and short computational time, while OTcl (object oriented extension of Tcl) is used for interaction between user and simulator.

6) WLANSim: WLANSim (*Wireless LAN Simulator*) [6] is an event-driven simulator developed by I. Tinnirello and G. Bianchi and it implements detailed characteristic of 802.11 MAC level [2], [4]. It is a tool to evaluate MAC performance in ad-hoc network based on IEEE 802.11b/g standard . It is developed in C++ with a modular structure that easily allows extension.

The goal of this work is the implementation of a simulator or an extension of a tool that takes care about physical parameters of the propagation environment. Furthermore it should be able to support smart antenna for device communication to enable performance evaluation of future standard extension based on directional antenna, like MIMO (*Multiple In Multiple Out*) [10], [29], [30], [31], [32], [33], [34], [35]. For these purposes we have decided to use as starting point WLANSim. It is developed as a collection of separated module so the development of extension and changes is easy. Furthermore it is fast in terms of simulation speed because it considers only the implementation of 802.11 MAC level.

B. WLANSim Overview

WLANSim is a tool developed in C++ and is able to evaluate MAC communication performances in wireless ad-hoc network. The simulator implements the access mode based on DCF (*Distributed Coordination function*) with all the details that are foreseen by the IEEE 802.11 standard. The access mechanism can be both basic and with RTS/CTS handshake. A recent extension of the same simulator provides the support for IEEE 802.11e [5] for QoS (*Quality of Service*) features.

The aim of the simulator is the evaluation of MAC level performance, so the **MAC** level itself is defined with high detail, while upper and lower levels implement minimal features and are identified by **Hi** and **Med** level, respectively. In Figure 1 an high level overview is shown. All the level here described can be associated a separate object in C++ language point of view.

The **HI** level contains the implementation of higher level and provides the generation and the receiving of packets for each station, both for AP and MS.

The **MAC** level implements all the features that are foreseen by the IEEE standard. It receives packets from upper level and sends them to the lower level. The MAC level takes into account also the busy channel condition and it provides the decrease of counters that storage information about busy channel duration. Furthermore it provides also interaction between HI and MED level: as we can see in details later, the interactions among levels do not occur directly, but they are done with generation of events that will be managed by the proper level.

The **MED** level implements the lower level of ISO/OSI standard. It does not provide the modulation and the error channel event: it considers the channel state (free to transmit or busy), the collision event (if more than one station transmit in the same time), the signaling for starting and ending the channel use, and the starting and ending of transmissions.
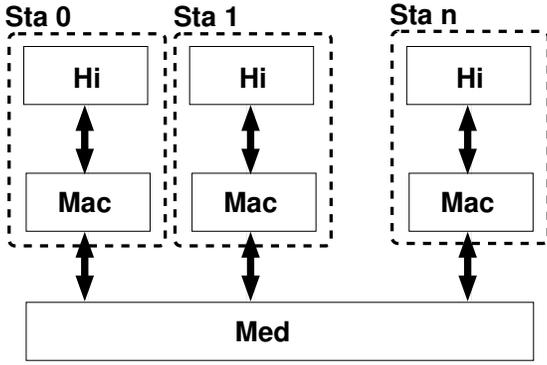
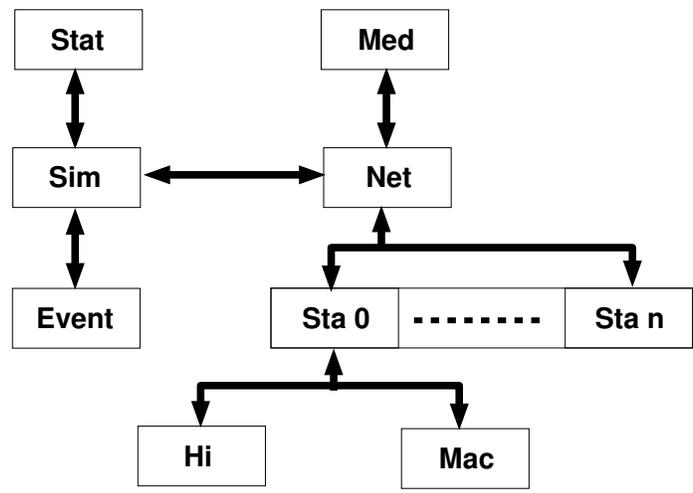Fig. 1.   Overall description of level interaction in WLANSim.

Fig. 2.   Detailed block structure of WLANSim.

C. WLANSim Detailed Structure

In Figure 2 a more detailed description of the structure of the simulator is shown. The figure represents the objects involved in the tool: each block showed in the figure can be associated to a C++ object (class or structure).

The **Event** block is the calendar of the simulator: it is the time-ordered collection of all the events that will be managed by the system. Every time an entity generates a new event it is put in the calendar in the right position accordingly to the time it will be managed. Each generated event has two time identifier: one shows the generation time and the second shows the schedule time (the time when it will be analyzed). The latter is used to put the event in the right position in the calendar. To reduce the amount of data in the calendar queue, when a event is manged it is removed and deleted from the queue.

The **Sim** block is the manager of the system: it initializes the system and manages all the events that are generated during the simulation. Its main tasks are *(i)* the taking the first event object in the calendar queue and *(ii)* the management of the same event with the forwarding to the proper entities.

The **Net** block receives all the events that must be managed by a station or by the Med object. the goals of Net are *(i)* the forwarding of the event to the proper level and *(ii)* the storage of the structure of the network in terms of number of involved devices.

The **Med** block implements the features of lower ISO/OSI stack levels. Every time a new event requests the sending of a new packet to the network, this block generates proper events to emulate the channel usage and the carrier sense. Furthermore it is able to check collision events on the medium and the correct transmissions between devices.

The **Sta** *X* blocks define the characteristics of the devices that are involved in the simulation. Each object storages information about the identifier of the station and some additional parameters, as enter and leave time in the simulation and generation packet rate. Furthermore all the objects are correlated to a Hi and Mac object: each device has its own Hi and Mac objects and these are uncorrelated with Hi and Mac objects of other stations.

The **Hi** and **Mac** blocks provide the features that are supported by HI and MAC level described in the previous Section II-B.

The **Stat** block collects all the parameters to evaluate network performances. Stat storages information about both devices (as number of transmissions, duration of transmissions, number of successful transmission, number of collisions...) and channel (as busy time, free time...). All the statistical parameters are printed in plain text output files.

D. WLANSim Extension

As mentioned above the WLANSim is a simulator that manages ad-hoc network, so the tool does not provide features about Access Point device. The first step of the work has been the extension of the tool to include feature of AP.

The major changes, detailed information, minor changes about input parameters of the simulator, and additional parameters for statistical purposes follow.

1) Insertion of AP devices: In WLANSim there is a structure that represents all the mobile station involved in the simulation. As from an high point of view, MS and AP have no differences, we decide to include the AP devices in this structure. Furthermore we have decide to use the following assumption: if the network involves N_{AP} AP and N_{MS} MS, the array is built considering the first N_{AP} element as AP and the following N_{MS} elements as MS. The identifier of each device is the index of the array element. In Figure 3 the structure for storaging of devices is shown.

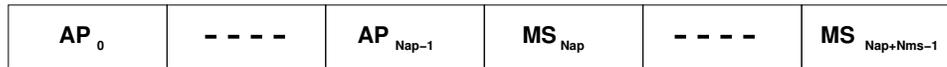| AP $_0$	- - - -	AP $_{Nap-1}$	MS $_{Nap}$	- - - -	MS $_{Nap+Nms-1}$

Fig. 3. Structure of array for storing of devices in WLANSim.

The WLANSim in the original version manages an ad-hoc network and the channel behavior is the same for all the stations. In an infrastructured network, the same condition isreliable when there is only one AP, so only one BSS (*Basic Service Set*). If we need to evaluate the performance of an ESS(*Extended Service Set*), so if we need to evaluate behavior of a network with more APs, a definition of multiple channel is mandatory. In a ESS more than one communication can be done in the same time without collisions, if the involved BSSs work on separated frequency bands.

2) AP behavior: In the original version of WLANSim the communication is directly between two devices, but in infrastructured mode the communication passes through the AP, so communication between two MS is differently managed. A mobiel device sends a packets and it is differently handled accordingly to the destination position, that is if the destination is in the same BSS or in another one.

If the sender and receiver are connected to the same AP, the procedure is:

- source MS sends a DATA packet;
- AP receives the DATA packet, sends an ACK packet to source and sends the DATA packet to destination device;
- destination MS receives the DATA packet and sends an ACK packet to the AP.

The MAC protocol provides a DIFS (*Distribute Inter-Frame space*) time before the sending of the packet to check if the channel is free and a SIFS (*Short Inter-Frame Space*) time between the complete receiving of DATA packet and the sending of the ACK packet. In the AP implementation, the ACK packet is sent after SIFS since the DATA packet is completely received, and after the ending of ACK transmission the AP waits SIFS and sends the DATA packet to the destination MS. With this time, the AP never occurs in collision.

If the sender and receiver are connected to different AP, the procedure is:

- source MS sends a DATA packet;
- AP$_1$ (which source MS is connected) receives the DATA packet, sends an ACK packet to source and sends the DATA packet to AP$_2$ which destination MS is connected;
- AP$_2$ receives the DATA packets and forwards it to destination MS;
- destination MS receives the DATA packet and sends an ACK packet to the AP$_2$.

In this case the communication between the two AP is an atomic event and it is not implemented in the simulator: delay due to wired communication are not considered. Furthermore the atomic event includes also the time that is requsted by AP$_1$ to know the address of the AP of the BSS where destination MS is. With this configuration the downlink communication (from AP$_2$ and destination MS) can cause a collision. AP$_2$ has no privileges and needs to contend the channel to transmit.

3) Traffic Directions: In an infrastructured network the flow of the packet can be associated to a *uplink* direction or a *downlink* direction, if the packet is sent over wireless channel by an MS or by an AP, respectively.

The simulator allows generation of type of traffic considering that source and destination of packet in the netwrok can be both wireless clients and remote clients that are out of evaluation environment (e.g. thei are wired clients that can be connected to the backbone network that connets the APs). The kind of traffic flows are:

Uplink: if the traffic sources are always and only MSs and the destination stations are not connected through wireless connection to the AP which the source station is connected;

Downlink: if the traffic sources are always and only APs and the destinations are MSs connected to the sending AP;

Local: if the MSs communicate each other using AP, and the APs never generate traffic.

III. PHYSICAL EXTENSION

In previous section the description of simualtor extensions are meant to introduce the concept of AP device and in this section we analyze the extension of the WLANSim tool to enhance the evaluation of channel propagation. The physical extension will be named PhySim.

The goal of the extension is to implements a software that is able to provide the characterization of the channel in wireless communication networks. PhySim tool is developed with the aim to produce a tool that is able to evaluate channel and communication error probability in a wireless environment, and that can be used with different simulator.

In this Section we describe the standard evolution and devices performance that the PhySim will support and then the structure of the system and its features. The integration with a "Hi Level" simulator is provided in general terms and in details for WLANSim.

A. 802.11b/g Extension

In the last years, after the growth of wireless LAN new standard are developed to enhance the performance of WLAN. After the first standard about frequency of 2,4 GHz (the IEEE802.11b [1], [2]) a new standard was developed: the IEEE802.11g [4]. In this extension new modulation schemes and transmission rates are developed to increase network performances keeping backward compatibility with IEEE802.11b. In this document we focus on 802.11b, but the same consideration can be extended to 802.11g standard. The plugin that manages wireless medium does not consider the modulation scheme: it considers only the transmission rate to evaluate the required time for transmitting a packet.

After new standard are developed to increase further the network performances, into details IEEE802.11e and IEEE802.11n.

The **IEEE802.11e** standard takes care about QoS features in 802.11b networks. In this documents, after an irrelevant changes of names that identify devices, introduces a new coordination function HCF (*Hybrid Coordination function*) that replaces the coordination functions foreseen by 802.11b/g, the PCF (*Polling Coordination Function*) and DCF (*Distributed Coordination Function*). The HCF is a mix of previous coordination functions and provides two access channel mechanisms: one is based on channel contention among stations to transmit, and the other is based on polling and is managed by a privileged station, usually the AP. In this paper we do not focus about features introduced by this standard, because they do not involve physical level and they are already partially included in the WLANSim.

The **IEEE802.11n** focuses the improvements of performances with changes of physical level, using smart antennas and SDMA (*Space Division Multiple Access*) technologies for channel access. This standard is still a draft version and two task group are working on it to converge to a standard. Nowadays there are commercial devices that use the new features that are defined in the draft, but the interoperability among devices from different vendors are not guaranteed. The use of SDMA techniques for channel access is provided by use of MIMO (*Multiple In Multiple Out*) antennas that allow the transmission (and the

receiving) of packet flow using more that one antenna. In this case the channel is divided into sub-portion for routing more packets simultaneously. Obviously this new features require changes both in MAC and in physical level.

B. Smart Antennas

The MIMO antennas should be used in devices support 802.11n standard and they can work in two manner:

Diversity mode requires the use of more than one antenna to increase probability to have a good path between transmitter and receiver. These multiple antenna can be only in the transmitter, only in the receiver or in both devices;

Spatial Multiplexing mode allows the transmission of packets using several channel over different frequency. In this case uncorrelated multipaths are required and in an ideal environment the channel capacity and number of antennas are linear dependent.

The 802.11b/g devices use one antenna for communication and it can be omnidirectional or directional. The use of directional antenna in standard Wi-Fi devices provides an increase of range for communication, a reduction of interference level and a better frequency reuse, but in any case the device can support only one transmission at the same time. The use of MIMO antenna or in general multiple antenna for transmitting and receiving requires changes in MAC protocol, because the 802.11b/g standard does not support multiple communication at the same time.

In literature, the antennas can be listed as:

Omnidirectional: the antenna has an uniform irradiation lobe over a plane. If an antenna has the same irradiation gain in all 3D direction, it is called *isotropic*;

Directional: the antenna has a non-uniform irradiation lobe and it can transmit or receive the maximum power in a particular direction. The direction with the highest gain is called *boresight direction*. This antenna is characterized by both its amplitude lobe (with related boresight direction) and its gain. The antenna gain is defined as the growth of the transmitted or received power related to the use of an isotropic antenna. The gain is usually measured in *dB* (decibel).

Array: the antenna is a collection of directional antenna and the boresight direction can be changed with alteration of single antenna phase and/or gain. This kind of antenna is also called **smart antenna**: it manages more than one antenna and can obtain best signal power using signal processing procedure to correctly configure the array [22]. Smart antennas can be listed as:

Switched beam: the antenna is made up of more than one lobe and each of them has a statical boresight direction. The lobe with the highest SIR (Signal to Interference Ratio) is used. These antennas can work in *single beam* mode if only one lobe is used to transmit or receive, or in *multi beam* mode if more than one lobe are used for communication at the same time;

Adaptative beam forming: the antenna has only one lobe and can modify the boresight direction accordingly to received SIR level. Furthermore the antenna can force zero gain in irradiation pattern in directions where interference signals are received. Also in this case the antenna can work in *single beam* mode if only one lobe is used and no multiple transmission are provided, or in *multi beam* mode if more than one communication at the same time are supported.

In the PhySim we use the description of antenna pattern in 2D dimension, so the irradiation patter is defined in a plane without loss of generality. A 3D pattern can be described with more lobe in different plane or with a rotation of a pattern over the boresight direction. An in depth description how the antenna designs are implemented in the simulator is shown in Section III-C.

C. PhySim: overall structure

In this section we describe the features of the PhySim, its development philosophy and finally a detailed description of the simulator. The structure and interaction with external MAC level simulator is shown in Figure 4
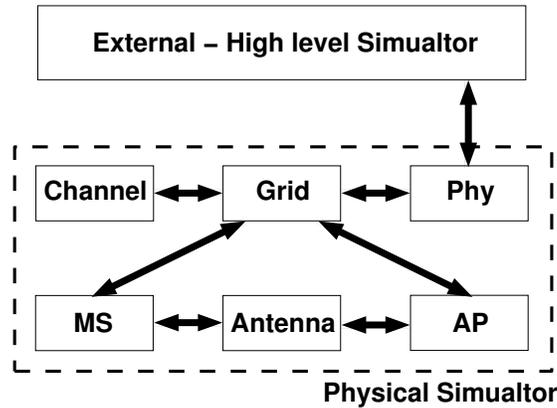

Fig. 4.   Block structure of PhySim.

The PhySim is a tool developed in C++ and its goal is to implement a description of both devices and environment involved in the simulations. In particular, it describes

Devices: they are the hardware involved in the simulation and they can be both APs and MSs. Their description is related in to physical description: position in the space, communication properties (like requested SIR for correct receiving, transmission power), and the antenna that the device uses;

Environment: it defines the place of the simulation. Its description can be done in 2D or 3D, and forbidden spots can be defined using a grid structure that is used to describe the environment;

Channel: it defines the characteristic of the channel to evaluate pathloss and receiving power. First approximation refers to an evaluation of received power using free pathloss formula with proper attenuation factor. Afterward more complex channel approximation can be implemented, for instance multipath, scattering, and fading.

All the elements that are described above, are related to an object in Figure 4 and each block can be assumed an independent C++ class. A detail description of each block with related interconnection follows:

Grid: this object is the core of the tool. It storages all the information about environment: the simulation place is supposed a rectangle where its dimensions can be defined by the user. The rectangle can be assumed as a grid where the dimension of single elements can be also defined by the user. This environment description allows a definition of an open space spot and i tis able to fix some forbidden cells (for instance, due to presence of obstacles or walls). The Grid object collects also information related device positions and geometrical parameters among devices. Furthermore it interacts with all other PhySim object so it is able to get all the information related to simulation;

MS: it is a collection of user devices. Each component object describes a MS in terms of physical parameters like position in the place, requested SIR for correct receiving, transmission power, and used antennas. All MS entities are uncorrelated: each element can be described separately;

AP: it is a collection of AP devices. Each component inherits the parameters from MS object and adds some additional information related to MS connected to itself. As MS objects, AP objects are also uncorrelated and can be described separately;

Antenna: it is a collection of objects which describe the irradiation lobe and gain of antennas that are used in the simulation. Each antenna element is described as an array of 360 elements

and each of them contains the antenna gain in the direction related to cell position in the array: the index of the array element is the offset related to boresight direction. Furthermore each Antenna object is characterized by an unambiguous identifier;

Channel: it describes the channel characteristic. Firstly a channel based on free-space path loss formula is implemented

$$P_r = P_t \cdot \frac{G_t \cdot G_r}{(4 \cdot \pi \cdot d/\lambda)^\alpha} \tag{1}$$

where P_t and P_r are the transmission and receiving power respectively, G_t and G_r are the transmission and receiving antenna gain respectively, d is the distance between the two devices, λ is the wave length, and α is the attenuation factor (equal to 2 for free-space and in the range (2, 4] for indoor environments). Afterward more complex scenario can be implemented considering fading and multipath;

Phy: it is the block that acts as interface between PhySim and an external simulator. With this development philosophy, the changes required in the external simulator are reduced to the minimum: you must add a new object in the proper class and all the required information can be gotten using interface functions in the Phy class.

D. PhySim: Interconnection with WLANSim

The philosophy below the PhySim development is to obtain an extension tool that is able to *(i)* define feature of physical communications, *(ii)* interact with external MAC level simulator, and *(iii)* require minor changes in external simulator. Related to the latter aspect, we have decided to implement an interface in the PhySim to interaction with higher level simulator: in external simulator we need to include a reference to the Phy object and then all the interface functions can be invoked.

In details, external simulator can get information about

- the received power level,
- the background noise level,
- the interference level,
- the received signal strenght (if the receiver is able to receive the signal), and
- the received packet reconstruction (if it is able to reconstruct correctly the packets).

In the latter two case all the physical information are managed only by PhySim tool, that informs higher level about communication conditions.

For implementation related to WLANSim, the major required changes are:

- the main file where the proper constructors for PhySim are required;
- the Med class, where a reference to PhySim is required.

Obviously, new functions for initiation of the references and changes in constructors are required.

It is important to underline that the implementation of PhySim is based on assumptions for the indexing of devices. In the WLANSim, the devices are identified as defined in Section II-D.1: APs have identifiers from 0 to $N_{AP} - 1$ and MSs have identifiers from N_{AP} to $N_{AP} + N_{MS} - 1$. In the PhySim, the AP identifiers are from 0 to $N_{AP} - 1$ and the MS identifiers are from 0 to $N_{MS} - 1$.

To invoke correctly the function of Phy class from WLANSim, we have two solutions:

- the Phy function receives the correct identifiers of sending and receiving stations;
- the Phy function receives the WLANSim identifier of sender and receiver and modifies them accordingly to its own enumeration.

The system implements the latter solution: all the functions used in the source file of WLANSim use the native indexing. The indexing use din PhySim is interned the simulator extension.

IV. RESULTS

In this section we shows some significant results related to simulation. Firstly we show comparison among results that are obtained by original WLANSim and the same simulator with PhySim extension. Obviously, in this case we need to evaluate a configuration like ah-hoc network, devices with omnidirectional antenna, and a channel without loss.

Afterward results related to use of WLANSim with PhySim extension for infrastructured network are shown. The devices can support omnidirectional or directional antenna and to obtain the same behavior of all MS we use a network configuration where the stations are on a circumference which center is the AP.

All the simulations are done using the same parameters that are shown in Table I

Parameter	Value
MSDU length	8184 bit
MAC header length	272 bit
ACK length	112 bit
PHY header length	128 bit
PHY bit rate	1 Mbps
DIFS time	50 μs
SIFS time	10 μs
slot time	20 μs
CW min	32 slot
CW max	1024 slot
TX power	100 $[mW]$

TABLE I

CONSTANT PARAMETERS FOR ALL THE SIMULATIONS.

Furthermore the simulation are done using all the possible combination of the following parameters:

$$
\text{Transmission rate} \quad \begin{cases} 1 & \text{Mbps} \\ 2 & \text{Mbps} \\ 5,5 & \text{Mbps} \\ 11 & \text{Mbps} \end{cases}
$$

$$
\text{Number of station} \quad \begin{cases} 2 \\ 6 \\ 10 \\ 15 \\ 20 \end{cases}
$$

$$
\text{Access mode with DCF} \quad \begin{cases} \text{with RTS} \\ \text{without RTS} \end{cases}
$$

A. Ad-hoc Network - Validation Results

In this section we compare the results provided by original version of WLANSim and the ones provided using the PhySim extension. The network is in ad-hoc configuration and the device parameters (as transmission power and requested SIR) are assumed to allow direct communication among all the stations: hidden terminals are not considered.

In Figure 5 and in Figure 6 the throughput of original version of WLANSim is shown without and with RTS/CTS handshake, respectively. Figure 7 and Figure 8 show the throughput of the same network tested in previous simulations using WLANSim and PhySim without and with RTS/CTS handshake, respectively. These graphs have the same behavior both with RTS/CTS mechanism and without RTS/RTS mechanism. The difference is a decrease of network performance due to the presence of management packets for

access channel. The simulation time is fixed, so if we use RTS/CTS mechanism the amount of useful packet (DATA packets) are smaller, because a portion of time is used by access control mechanism. In the following session only results related to case with RTS/CTS mechanism will be shown.

In Figure 9 and in Figure 10 the packet loss percentage of original version of WLANSim is shown without and with RTS/CTS handshake, respectively. Figure 11 and Figure 12 show the packet loss percentage of the same network tested in previous simulations using WLANSim and PhySim without and with RTS/CTS handshake, respectively. These graphs takes into account the number of loss packets due to collision event on the channel, because the ideal medium does not cause receiving errors. Furthermore, when RTS/CTS mechanism is used the packet loss percentage is evaluated using also collision events that happen during access channel mechanism. If we consider only packet loss percentage over DATA packets, it will be always zero because, as described before, collisions are the only cause that produces packet loss.
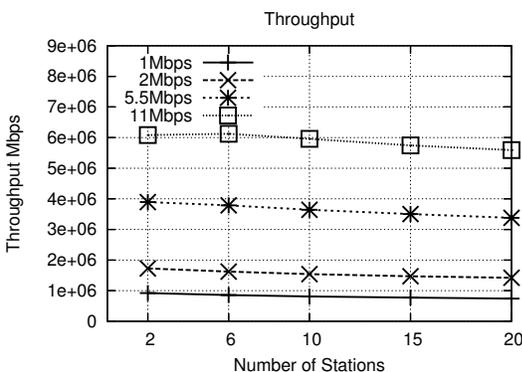
Fig. 5. Throughput in ad-hoc network with WLANSim and without RTS/CTS.
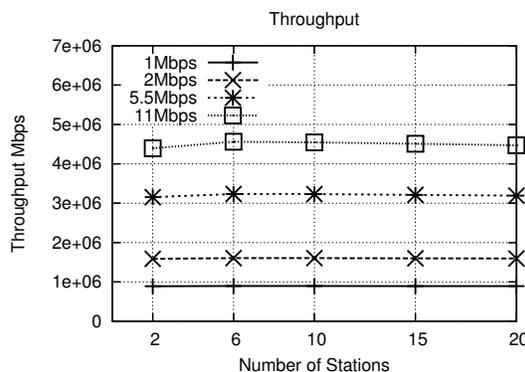
Fig. 6. Throughput in ad-hoc network with WLANSim and with RTS/CTS.
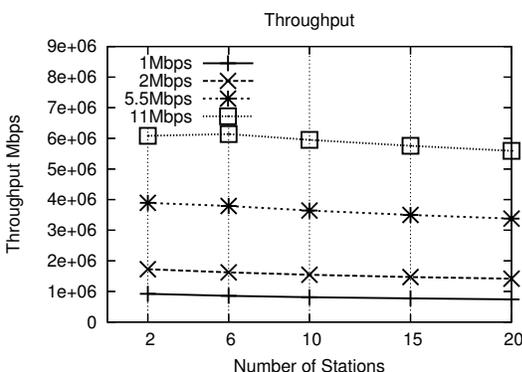
Fig. 7. Throughput in ad-hoc network with PhySim extension and without RTS/CTS.
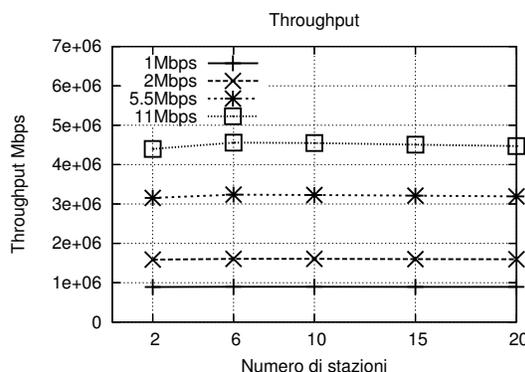
Fig. 8. Throughput in ad-hoc network with PhySim extension and with RTS/CTS.

B. Infrastructured Network - Omnidirectional Antenna

In this section we show some preliminary results related to use of WLANSim with PhySim extension for infrastructured network. The device positions are over a circle which center is the AP device and no hidden terminal conditions are considered.

Figures 16 16 show the behavior of single station in infrastructured configuration with 6 MS and 1 AP, with transmission rate of 1 Mbps and 11 Mbps, respectively. Figures ?? ?? show the behavior of single station in infrastructured configuration with 20 MS and 1 AP, with transmission rate of 1 Mbps and 11 Mbps, respectively.
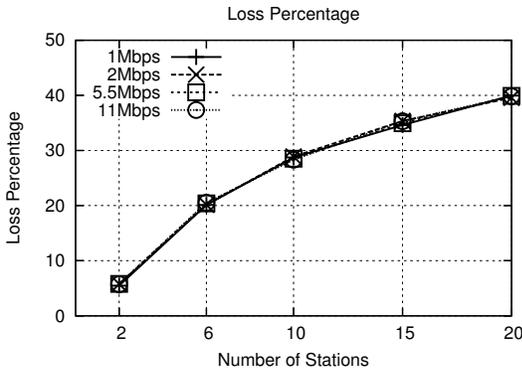
Fig. 9. Packet loss percentage in ad-hoc network with WLANSim and without RTS/CTS.
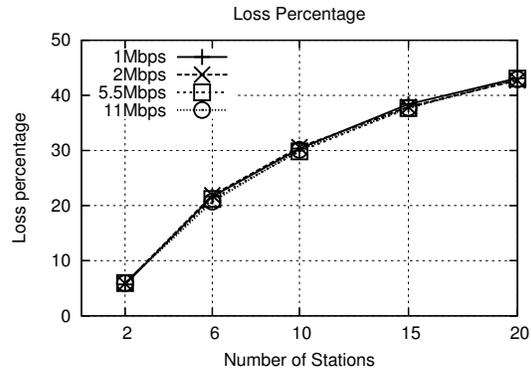

Fig. 10. Packet loss percentage in ad-hoc network with WLANSim and with CTS/RTS.
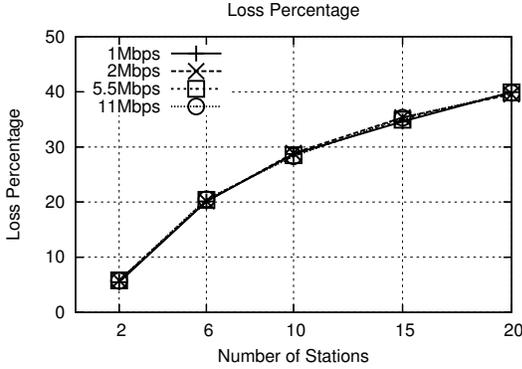

Fig. 11. Packet loss percentage in ad-hoc network with PhySim extension and without CTS/RTS.
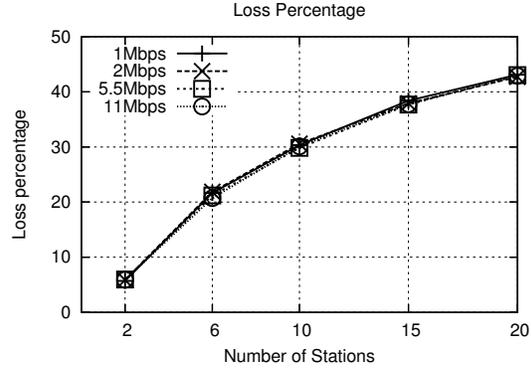

Fig. 12. Packet loss percentage in ad-hoc network with PhySim extension and with CTS/RTS.

Figures 17 18 show the throughput and collision probability for a network which devices use RTS/CTS access mechanism. The network performances without RTS/CTS mechanism have the same behavior but with high throughput: the cause is previously described in Section IV-A.

C. Infrastructured Network - BeamForming Antenna

In this section we show some preliminary results related to use of WLANSimwith PhySim extension for infrastructured network with devices equipped with beam forming antenna. The device positions are over a circle which center is the AP device and no hidden terminal conditions are considered.

Figures 22 22 show the behavior of single station in infrastructured configuration with 6 MS and 1 AP, with transmission rate of 1 Mbps and 11 Mbps, respectively. Figures **??** show the behavior of single station in infrastructured configuration with 20 MS and 1 AP, with transmission rate of 1 Mbps and 11 Mbps, respectively.

Figures 23 24 show the throughput and collision probability for a network which devices use RTS/CTS access mechanism. The network performances without RTS/CTS mechanism have the same behavior but with high throughput: the cause is previously described in Section IV-A.

Figures 24 26 show the throughput and collision probability for a network which devices use RTS/CTS access mechanism. The network performances without RTS/CTS mechanism have the same behavior but with high throughput: the cause is previously described in Section IV-A.
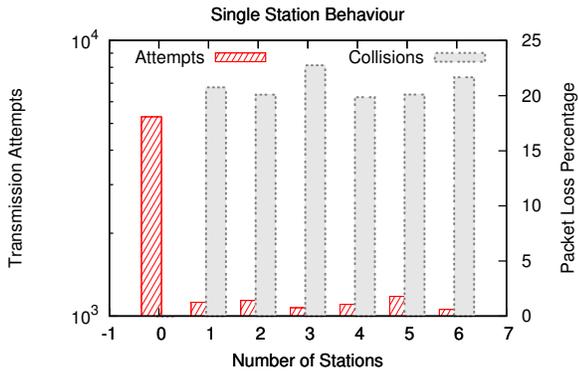
V. CONCLUSION

TBD

Fig. 13. Single station behavior with 6 MS, 1 AP, 1Mbps transmission rate and no RATS/CT'S mechanism.
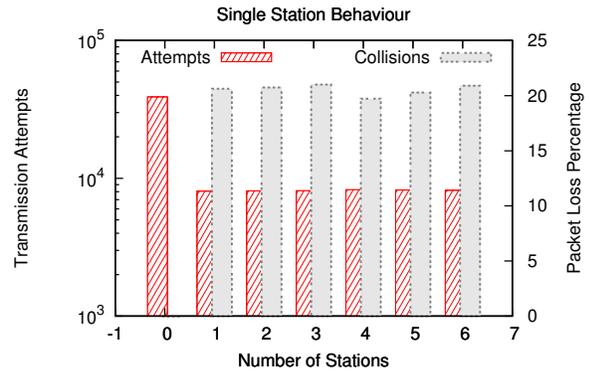

Fig. 14. Single station behavior with 6 MS, 1 AP, 11Mbps transmission rate and no RTS/CTS mechanism.
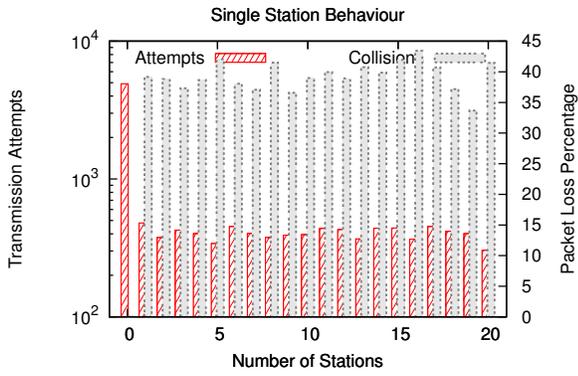

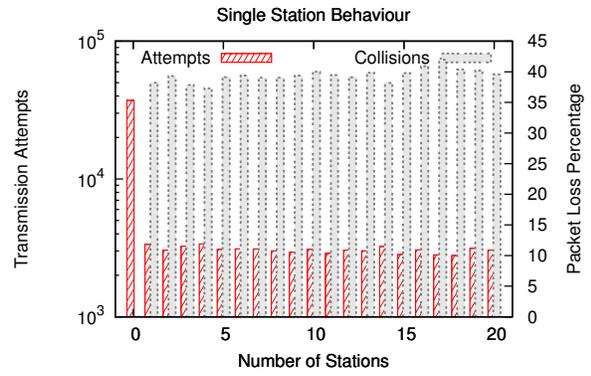Fig. 15. Single station behavior with 20 MS, 1 AP, 1Mbps transmission rate and no RTS/CTS mechanism.

Fig. 16. Single station behavior with 20 MS, 1 AP, 11Mbps transmission rate and no RTS/CTS mechanism.
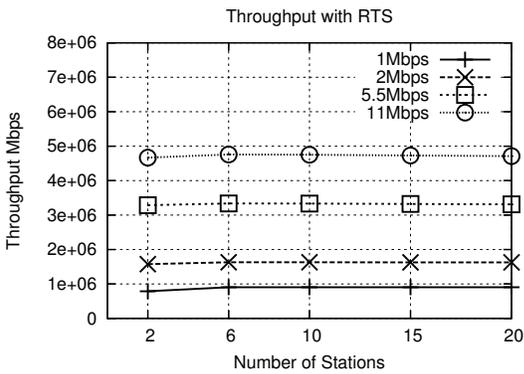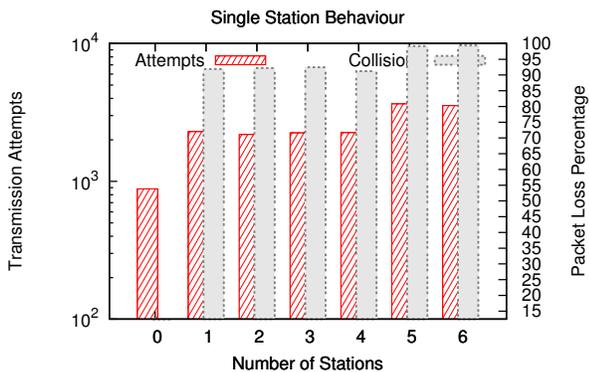

Fig. 17. Throughput in infrastructured network with omnidirectional antennas and CTS/RTS.
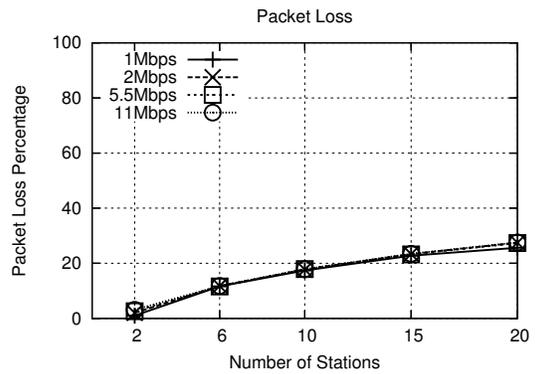
Fig. 18. Packet loss percentage in infrastructured network with omnidirectional antennas and CTS/RTS.

Fig. 19. Single station behavior with 6 MS, 1 AP, 1Mbps transmission rate and no RTS/CTS mechanism.
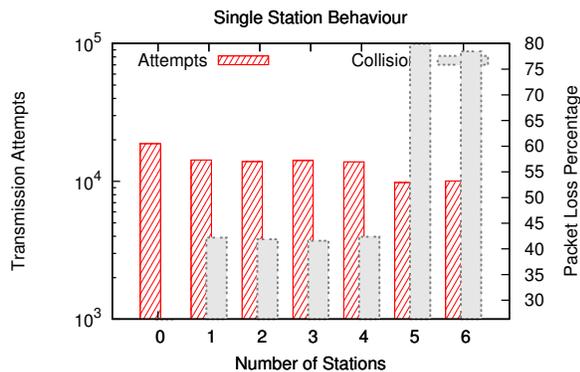

Fig. 20. Single station behavior with 6 MS, 1 AP, 11Mbps transmission rate and no RTS/CTS mechanism.
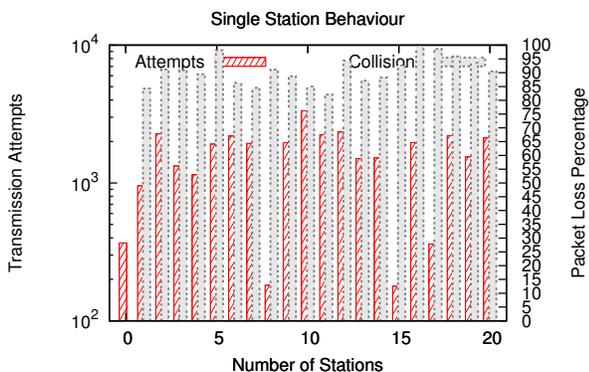

Fig. 21. Single station behavior with 20 MS, 1 AP, 1Mbps transmission rate and no RTS/CTS mechanism.
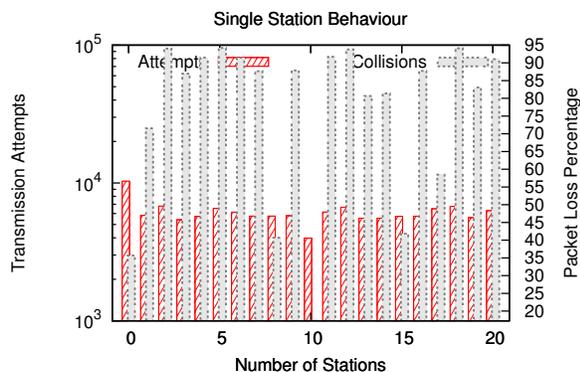

Fig. 22. Single station behavior with 20 MS, 1 AP, 11Mbps transmission rate and no RTS/CTS mechanism.
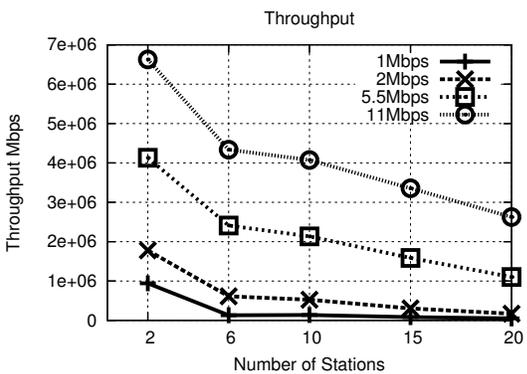

Fig. 23. Throughput in infrastructured network with omnidirectional antennas and without CTS/RTS.
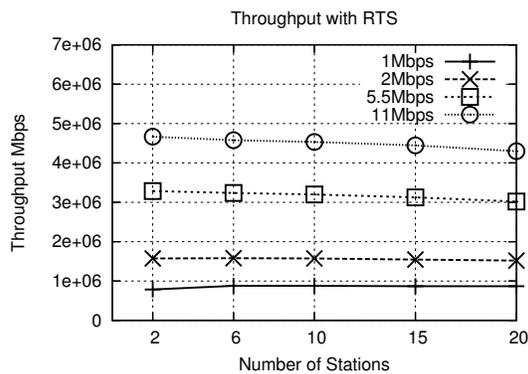

Fig. 24. Throughput in infrastructured network with omnidirectional antennas and CTS/RTS.
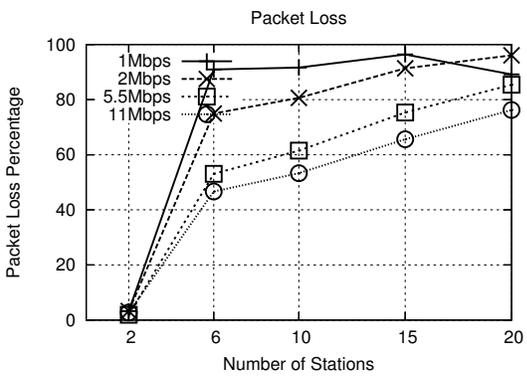
Fig. 25.   Packet loss percentage in infrastructured network with omnidirectional antennas and without CTS/RTS.
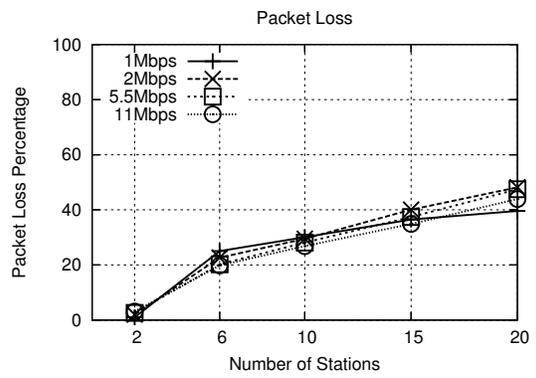

Fig. 26.   Packet loss percentage in infrastructured network with omnidirectional antennas and CTS/RTS.

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