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A NEW ALGORITHM FOR OPTIMIZING IEEE 802.11 NETWORK BASED ON INTERFERENCE ACTIVITY EVALUATION CRITERIA

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Abstract- In actual crowded networks, the use of Partially Overlapped Channels for IEEE 802.11 networks is a practical solution. That is way the paper is proposing a new general model and algorithm which is focused on interference evaluation and avoidance in order to improve network operation performance. The model includes available passive monitoring devices/software and combines real-time and recorded experimental data associated with the interference existence/behavior on site environment, building an algorithm and data base finally aimed to optimize frequency planning. The paper also proposes a general model and evaluation criteria for the effect of interference link utilization, taking into account that interference link utilization is less analyzed but its importance was already confirmed by [2, 7]. The paper finally proposes a general approach for a cognitive optimization model/subroutine for IEEE 802.11 networks planning improvement.

Keywords: IEEE 802.11 Networks, Interference Factor, Interference Link Utilization, Networks Planning.

I. INTRODUCTION AND RELATED WORKS

The IEEE 802.11 standard provides a small number of non-overlapping channels, in both non-licensed bands (2.4 GHz; 5 GHz). Consequently, the use of Partially Overlapped Channels (POC) for IEEE 802.11 networks is a solution often proposed [1, 2, 3, 5, 8].

On the other hand, the proliferation of IEEE 802.11 devices in the mentioned non-licensed bands is confronted with multiple interference sources, with both internal and external causes, including adjacent channels. As main consequences, throughput decrease and lost packets high rates will be present.

The IEEE 802.11k standard brings some support information for the radio resource management [11], including wireless interference records only for the channel utilization generated by non-802.11 devices, but does not give details about the methods to collect these data [10]. In order to evaluate Signal to Interference and Noise Ratio (*SINR*), a parameter called *interference factor* is already approached in [1, 3].

We have also used the *interference factor*, but we propose a general model and algorithm which is focused on interference evaluation and avoidance in order to improve network operation performance. The model includes available passive monitoring devices/software and combines real-time and recorded experimental data associated with the interference existence/behavior on site environment, building an algorithm and data base finally aimed to optimize frequency planning.

The interference link utilization is still less analyzed, but its importance was already confirmed by [2, 7]. The actual paper, in addition, proposes a general model and evaluation criteria for the effect of interference link utilization. The link utilization management is a complex problem which is closely linked with the medium occupied time for radio resource management, in IEEE 802.11 networks [10].

As a matter of fact, Seung-Chur Yang et al. present an interesting and nearly complete approach considering all components of the Medium Occupied Time (MOT): DBT, SBT and PBT. Sense Busy Time (SBT) is defined as the time when a radio signal is sensed but is not decodable to a frame by an observing node, while Data Busy Time (DBT) is the time duration where a radio signal is sensed and the signal is decoded to frames. Protocol Busy Time (PBT) is defined as the time gap necessary for MAC protocols. PBT is categorized as logical MOT, while SBT and DBT are physical parts of MOT. Usually SBT is generated by hidden nodes, nodes on adjacent channels and non-802.11 devices, but the measuring node cannot detect them. Seung-Chur Yang et al. demonstrate that the state-of-the-art research, using the known method of the frame parser and the register monitor, cannot measure all the three components of MOT and especially SBT which includes non-802.11 devices. On this line, 2 relevant examples are given.

Dely et al. present an analytical model to study the channel busy fraction in nonsaturated IEEE 802.11 networks, but the model does not include an interference channel (i.e. MOT without SBT) [12]. The second example is where Lakshminarayanan et al. propose a new framework using an off-the-shelf wireless device which could provide a time diagram describing how the radio channel is used [13].

They are focusing on identifying the sources of interference from non-802.11 devices and finally it results that the approach is not suitable for identifying non-802.11 sources in IEEE 802.11n networks [10]. Consequently, Seung-Chur Yang et al. conclude that an empirical analysis for SBT and PBT is required to exploit MOT in a real environment.

For our work, [10] is a good confirmation of the interest for deeply evaluating the interference effects and mainly of the opportunity of the empirical approach, as analytical solutions for SBT do not exist. This will also reveals the importance of using, as an added data resource, the experimental data from the real site environment, i.e. our new algorithm approach.

Our paper is also aiming to extend our results from [4] and [6] in order to get a new general theoretical model, experimental results and a better evaluation and avoidance of the interference by building an algorithm associated with a data base, finally used to optimize frequency planning.

The main contributions to achieve these purposes are made by combining real-time and recorded experimental data on the interference existence/behavior on site environment. The rest of the paper is organized and presents contributions as in Section II - Models and algorithms (Interference factor evaluation; Evaluation of Interference Link Utilization Influence; Cognitive optimization model and subroutine for IEEE 802.11 networks planning), in Section III - Experiments and results and Section IV - Conclusions.

II. MODELS AND ALGORITHMS

Our reference experimental model consists in one access point (AP1) and 2 laptops (link 1), as could be seen in Figure 1. The PC1 laptop is connected to AP1 via cable and the PC2 is using a wireless IEEE 802.11g connection. On the PC1 is installed the *Jperf* and *inSSIDir* soft packages [9] while PC2 is configured as a work station.

The complete experimental configuration is presented in Figure 1 and consists in link 1 with another access point (AP2) and 2 laptops (PC3 and PC4). AP2, PC3 and PC4 (link2) are connected in a configuration which is similar to the above presented reference experimental model. We used as access points "*Tenda W316R*" routers while the network card for laptop is "*Qualcomm Atheros AR5BWB222*".

The communication performance parameters of AP1 users are subject of interference caused by AP2 when performing data transmissions on variable channels around the useful channel 6 assigned for the desired link (AP1-PC2).

The main variation factors considered for the interference caused by AP2 are the spatial AP2-AP1 distance and the channel spacing.

More than these, in our paper the role of the interference utilization will be analyzed in a separate section, where IEEE 802.11 standard Clear Channel Assessment (CCA) and Distributed Coordination Function (DCF) mechanisms are also considered.

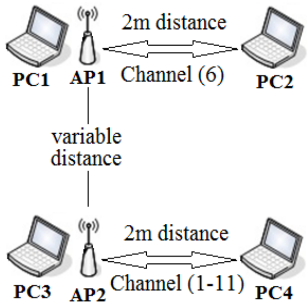

Figure 1. Experimental platform for interference evaluation

A. Model and Algorithm for Interference Factor Evaluation

Extending [1] approach for the interference factor (IF), we considered a more general model formalizing the dependence of IF on frequency and distance, i.e. both frequency and spatial separation between desired and jamming link, in order to estimate the interference influence.

In order to obtain a higher accuracy of practical results of the model and algorithm, in general the goal is to consider the factors that could determine the interference influence: channel spacing of POC and IEEE 802.11 standard spectral mask.

Because the interference caused by POC is reducing the maximum channel throughput, it is important to evaluate Adjacent Channel Interference (ACI), as it is also confirmed by [8].

The IEEE 802.11 standard spectral mask has a reference influence on analyzing *SINR* and a typical diagram of this mask (for Direct Sequence Spread Spectrum) is presented in Figure 2.

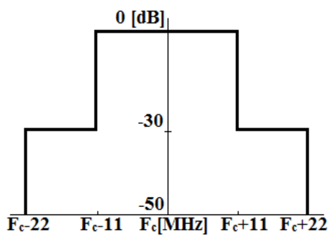

Figure 2. A diagram of IEEE 802.11 DSSS mask

ACI are generating interference effects that could be evaluated by the interference factor (IF) as [1]:

$$I_{u,i}(F) = \int_{-\infty}^{+\infty} P_{Em}(f) \cdot P_{Rec}(f - F)\,df \quad (1)$$

In the previous equation, $P_{Em}(f)$ and $P_{Rec}(f)$ are respectively the transmitted signal spectrum and the frequency response of the receiver filter. Also, $F = |F_u - F_i|$ is the difference between the central frequencies (i-transmitter and u-receiver).

In Figure 3 we present the equivalent scheme of the experimental platform (Figure 1), for the further estimation of $I_{u,i}$.

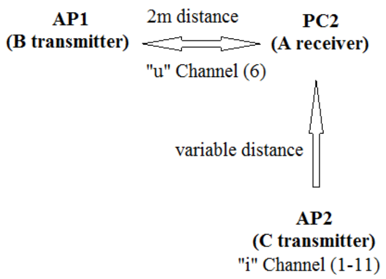

Figure 3. The equivalent scheme of the experimental platform

For usual values the noise level is much lower than the interference one and with a good approximation we can neglect it. Consequently, *SINR* will be approximated as Signal to Interference Ratio (*SIR*):

$$SIR = \frac{P_{Rec}\{B \to A\}}{P_{Rec}\{C \to A\}} \quad (2)$$

The transmitted power will become, at the receiving point:

$$P_{Rec} = \frac{P_{Em} G_{Em} G_{Rec} \lambda^2}{(4\pi)^2 d^2 L} \quad (3)$$

In the previous equation, we noted by P_{Rec} and $P_{Em} (G_{Rec}, G_{Em})$ the powers at receiver and transmitter (the gains of receiving and transmitting antennas). Also, we noted by λ the wavelength, by L the loss factor and by d the separation space from the emitting to the receiving point.

Considering (3) for the link 1 we have

$$P_1 = \frac{P_{Em}\{B\} G_{Em}\{B\} G_{Rec}\{A\} \lambda^2_{\{B \to A\}}}{(4\pi)^2 d_{\{B \to A\}}{}^2 L} \quad (4)$$

and then for link 2

$$P_2 = \frac{P_{Em}\{C\} G_{Em}\{C\} G_{Rec}\{A\} \lambda^2_{\{C \to A\}}}{(4\pi)^2 \cdot d_{\{C \to A\}}{}^2 L} I_{u,i} \quad (5)$$

where, $I_{u,i}$ is IF between useful (u) and interference (i) channels, as $P_1 = P_{rec}\{B \to A\}$ and $P_2 = P_{Rec}\{C \to A\}$.

For simplicity, without losing the generality, we further suppose equal powers, antenna gains and loss factors for both links:

$$P_{Em}\{B\} = P_{Em}\{C\} \quad (6)$$

Then SIR could be expressed as:

$$SIR = \frac{1}{I_{u,i}} \left(\frac{d_i}{d_u} \right)^2 \left(\frac{f_i}{f_u} \right)^2 \quad (7)$$

For a simpler starting point we can also consider

$$d_{\{B \to A\}} = d_{\{C \to A\}} \quad (8)$$

From the IEEE Standard 802.11 channels separation, it results that ACI is produced if

$$f_i = f_u + k \cdot 5 \text{ MHz} \;,\; k = \overline{1,\ 4} \quad (9)$$

$$\frac{S}{I} = \frac{1}{I_{u,i}} \left(\frac{f_u + k \times 5 \text{ MHz}}{f_u} \right)^2 \quad (10)$$

The Shannon's relation for channel capacity is

$$C = B \log_2 \left(1 + \frac{S}{N} \right) \quad (11)$$

Considering again the fact that for usual values the noise level (N) is much lower than the interference one (I), $I > N + 80$ dB, with a good approximation we can neglect it and then

$$C = B \log_2 \left(1 + \frac{S}{I} \right) \quad (12)$$

As a consequence, *SIR* will be given by:

$$\frac{S}{I} = 2^{\frac{C}{B}} - 1 \quad (13)$$

Then, using (10), we have:

$$I_{u,i} = \frac{1}{2^{\frac{C}{B}} - 1} \left(\frac{f_u + k \times 5 \text{ MHz}}{f_u} \right)^2 \quad (14)$$

The k factor has values (1, 2, 3, 4) according to the situation of the overlapping in the IEEE 802.11 allocation.

B. Model and Algorithm for the Evaluation of Interference Link Utilization Influence

The necessity of deeply evaluating the interference effects and mainly of the empirical approach was also presented by [10], as analytical solutions for SBT do not exist. They also confirmed the importance of using, as an added data resource, the experimental data from the real site environment, i.e. our new algorithm approach.

In the more general context of MOT, Seung-Chur Yang et al. also showed that SBT is generated by hidden nodes, nodes on adjacent channels and non-802.11 devices, but the measuring node cannot detect them [10].

More than these, the IEEE 802.11k standard provides wireless interference records only for the channel utilization generated by non-802.11 devices without offering methods to collect these data [10], [11].

This context reveals the necessity of searching new models in order to deeply evaluate the interference effects. As analytical solutions for SBT do not exist, the empirical approach is also proved to be necessary for improving interference effect estimation [10], [15].

The same context confirmed the importance of using, as an added data resource, the experimental data from the real site environment, as our new model and algorithm will also include in a general approach. The role of Interference Link Utilization (*ILU*) is less analyzed, but its importance was already confirmed by [2].

The experiments and conclusions of [2] and [7] also confirmed the importance of data rate (r) of interference and the fact that when this rate grows, *ILU* decreases. This effect is increasing as r is increasing and it is linked with constellation complexity and DCF.

Therefore we can model *ILU* by the next equation:

$$ILU = (1/r)\, C_U \quad (15)$$

where, C_U is a network scenario parameter depending on the number/position of transmitters by the CCA and DCF mechanism.

Considering the approach of [5], the effective link-layer data rate on link (r) is depending on IEEE 802.11 nominal data transmission rate r_0 (for example 11 Mbps) weighted by the link activity factor F_{link} (the fractional time when interference is operating):

$$r = r_0 F_{link} \tag{16}$$

with, $0 \le F_{link} \le 1$ and then,

$$ILU = \frac{1}{r_0 F_{link}} C_U \tag{17}$$

As generally it is very difficult to determine F_{link} and C_U, we propose an approximation (reference value as a function of network concrete scenarios) which could be estimated from experimental data.

The parameter F_{link} also depends on active/idle processes (provided by CCA and DCF) and generally on the environmental transmitters (internal or external to the network). Consequently, it is interesting to consider a cognitive approach of the general model for the interference utilization factor (*IUF*), as an arbitrary function (f):

$$IUF = (C_U / F_{link}) f(ACTivity, CONtext) \tag{18}$$

In the equation (18) *ACTivity* is a formal parameter depending on the concrete activity (portion of time where the interferer is active) of the interference. *CONtext* is a parameter reflecting the consequences of interference rate, as the transmission-idle time and the environmental transmitters. Generally *ACTivity* is depending on interference behavior (including time or concrete associated data).

The above definition (modeling) of *IUF* is formally useful, as it presents practical reasons to use the experimental data (as lost packet statistics) in order to extract estimative information on interference behavior (IB) and then using it in associated scenarios for improve network health/planning.

Practically, IB means that in a general model approach (eventually subroutine) we can establish concrete relations between the effect (level; time) of interference on our network and a limited set of scenarios.

Such scenarios could include interference existence, position, behavior and activity and they could provide approximate values for *ILU* in order to use these values to correct the expected level of interference effect in every scenario. Based on these values, then we could adjust the network planning (frequency re-use; power control; nodes deployment etc.) and finally optimize (or at least improve) the network operation/health.

As a consequence, we can write *ILU* as

$$ILU = (1/r_0)\ IUF \tag{19}$$

Finally we can use *ILU* to correct (weight) the $I_{u,i}$ values by *ILU* corresponding values in order to find the best planning solution as function of channel and position (distance) as minimum I_{av}, with

$$I_{av} = (1/n) \sum_{u,i} (ILU) I_{u,i} \tag{20}$$

where, n is the number of active links of the IEEE 802.11 network.

ACTivity and *CONtext* contain information that could be obtained, in the general case, only by monitoring the environmental activity, as we propose, by different hard/soft means, as spectrum analyzers/sniffers and specialized soft packages [4, 9].

For instance, we can use the results of *Jperf* soft package which can provide lost packets statistics, by a set of runs in different scenarios for channel/distance configuration and for activity/traffic of the interference.

From a refined analysis of these runs, adding experimental reference data where rate and activity is known, relevant information associated with lost packages (or throughput) could be extracted from the statistics (similar but larger than in Table 1).

As a final result, good estimates for f(*Activity*,*Context*) values could be obtained and then implemented in the cognitive model/subroutine of network planning optimization, as it will presented in a next section.

Analyzing and integrating the sets of experimental data we can also obtain an estimate/trend for the packet error rate (lost packets), which reflects the effect of the interference on throughput and also the interference existence, positions and behavior.

In a further development phase, using learning techniques and algorithms, the results could reveal interference or networks behavior which could be stored (as data bases or expert systems) and then used in real time applications.

C. Cognitive Optimization Model and Subroutine for IEEE 801.11 Networks Planning (COMSINP)

The objectives of optimization include throughput, lost packets, frequency re-use, nodes deployment and eventually the energy (battery) consumption (because many applications include mobile devices).

Network frequency planning could benefit from using overlapping channels (POC) as many papers confirmed [2, 3, 14]. In addition we propose a new model to integrate the factors which are supposed to leverage this benefit by exploiting real time/scenario data. The model includes experimental data which are focused on knowing more about the random situation of environmental interference and finally on lowering its negative effect.

COMSINP is a development frame model and subroutine, where the above theoretical basics and experimental platform are generalized for n active links of IEEE 802.11 network and for further developed hard/soft tools.

The general model of COMSINP is implemented in a subroutine consisting of the next steps:

1. Set the network configuration and parameters (CONFIG; PARAM);

- CONFIG includes the number of access points (AP), users and their relative distances/positions.
- PARAM provide the communication frequency channels, rates and other settings of AP and user, like power level (regime) or autorating.

2. Determine the interference existence and scenario (IEXIST; ISCEN);

- IEXIST includes the next steps:
2.a Use available devices/soft packages (like *inSSIDir*) to determine actual frequency spectrum occupancy and power levels;
2.b Evaluate throughput and lost packets with performance analysis instruments (like *Jperf*);
- ISCEN includes the next steps:
2.c Introduce IEXIST data from 2.a and 2.b in the existing interference data base (IDB);
2.d Use IDB to select the stored scenario which best match actual scenario expressed by 2.a and 2.b results.
3. Evaluate (extract) $I_{u,i}$ which is associated in IDB with ISCEN for every active link;
4. Improve actual $I_{u,i}$ by selecting the scenario which provides the lowest I_{av}.
If the actual I_{av} is the lowest, go to 6;
5. Go to 1.
6. Stop until the new programmed monitoring time and then go to 1.

III. EXPERIMENTS AND RESULTS

The experimental work was performed on the experimental platform for interference evaluation (Figure 1). The experiments focused on observing and evaluating the interference effect produced by AP2, which performed data transmissions on variable channels around the useful channel 6 assigned for the desired link (AP1-PC2).

Using *Jperf* application we have obtained the results in Figures 4 and 5, where throughput is presented versus *SINR*, for a diversity of scenarios having parameter the distance and the channel spacing between user link (AP1) and interference (AP2).

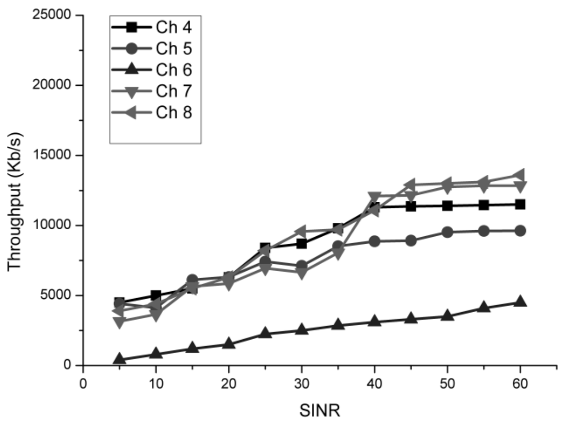

Figure 4. Throughput versus *SINR*, for 8m AP2-AP1 distance

The presence and the effect of ACI interference (modeled in section II.A) is considerably affecting the reference link 1 (AP1 operation), as we can see a degradation of throughput performance exceeding 5 Mbps in any case.

The graphics represented in these figures show an increase of the desired throughput with the two links channel spacing. When this spacing is zero (AP2 on channel 6) the throughput drop is dramatic (link 1 is nearly down).

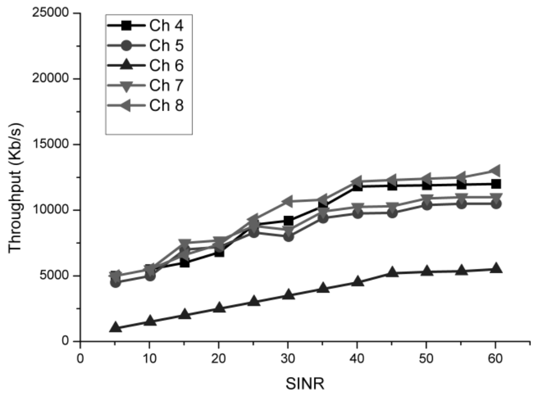

Figure 5. Throughput versus *SINR*, for 12m AP2-AP1 distance

Still, we can observe that the effect of interference caused by the factor of frequency separation (number of channels) is considerably attenuated at poor *SINR*. This is the main reason the curves (in both Figure 1 and Figure 2) are difficult to be distinguished for *SINR* lower than 20 dB.

The last observation is a confirmation of the realistic experimental results and proposed IF algorithm represented by these graphics, due to the fact that usually, for a good communication link, *SINR* exceeds 20 dB.

Another important observation is given by the dependency of interference effect on distance between AP2 and AP1. Consequently we can see, on Figure 5, that when AP2 is moved away from AP1 the throughput is increasing. Although this increase is visible for all graphics, it is not high (when distance is increased from 8m to 12m).

That is why we may point a very important observation concerning the fact that the effect of interference is strongly depending on ACI existence and less on separating distance, for common range of distances (like 8m/12m). Consequently, such throughput versus *SINR* results could obviously be analyzed and be useful for network planning improvements.

Using *Jperf* application we have also conducted a set of experiments having as results the statistics of lost packets, under the impact of interference in a diversity of scenarios, as presented in Table 1.

The most visible parameters considered in those scenarios are the channel of AP2 operation and the separating distance. Besides, the different runs are reflecting variations of AP2 operation (activity; traffic; rate) in time, in order to simulate *ILU* variations and interference behavior.

Table 1. Lost packets for different channel/distance

Ch-Dist /Run	1	2	3	4	5
4-6m	0.32%	0.34%	0.36%	0.28%	0.29%
4-10m	0.21%	0.28%	0.34%	0.26%	0.25%
5-6m	0.35%	0.37%	0.40%	0.37%	0.41%
5-10m	0.24%	0.32%	0.35%	0.34%	0.36%
7-6m	0.58%	0.41%	0.43%	0.52%	0.39%
7-10m	0.27%	0.31%	0.28%	0.33%	0.48%
8-6m	0.38%	0.36%	0.42%	0.35%	0.44%
8-10m	0.25%	0.22%	0.31%	0.27%	0.22%

The statistics of lost packets alone do not give much information, but anyway it is obvious in Table 1 that the negative effect of interference increases as channel spacing (Ch) is decreased and same trend is with the distance (Dist).

The general model for *ILU* will benefit of much more information if statistics are obtained in a programmed sequence of scenarios where the interference is precisely associated (and measured). With other words, we must associate with every experiment set/Run (as we presented, just as potential examples, Run = 1, 2, 3, 4 and 5 in Table 1) the interference features/parameters: existence, position, activity/power, data rate, time reference and generally behavior.

Consequently, if the experiment will be conducted in a complex platform which provides all the necessary instruments to quantify the above features, then the statistics could be integrated in IDB. The integration will include and quantify all the features/parameters that could be associated with every interference scenario. Then these data will be used as presented at step 3 of COMSINP in section II.C.

IV. CONCLUSIONS

The paper main contribution is a general model and algorithm which is focused on interference evaluation and avoidance in order to improve network operation performance. The model includes available passive monitoring devices/software and combines real-time and recorded experimental data associated with the interference existence/behavior on site environment, building an algorithm and data base finally aimed to optimize frequency planning.

The general model and algorithm is based on 3 modules. The first module is the Model and Algorithm for Interference Factor (IF) Evaluation. Extending [1] approach, we considered a more general model formalizing the dependence of IF on frequency/distance by adding experimental data for analysis and the optimization algorithms of network performance.

The second module is a new general Model and Algorithm for the Evaluation of Interference Link Utilization Influence, taking into account that interference link utilization is less analyzed, but its importance was already confirmed by [2] and [7]. More than this, [10] is a good confirmation of the interest for deeply evaluating the interference effects and mainly of the opportunity of the empirical approach, as analytical solutions for SBT do not exist. This reference also reveals the importance of using, as an added data resource, the experimental data from the real site environment, i.e. our new algorithm approach.

The paper finally includes the third module, as a general approach for a Cognitive Optimization Model and Subroutine for IEEE 802.11 Networks Planning (COMSINP) improvement.

It is very important to point that COMSINP in fact integrates the other two modules and the added experimental data for analysis and optimization algorithms.

The presented experiments and results include network throughput presented versus *SINR*, for a diversity of scenarios having parameter the distance and the channel spacing between users link (AP1) and interference (AP2). Here a first observation is concerning the fact that the effect of interference is strongly depending on ACI existence and less on separating distance, for common range of distances (like 8m/12m) . The main observation, as it is above mentioned, is that the graphics from Figure 1 and Figure 2 confirm the realistic experimental results and proposed IF algorithm represented by these graphics, due to the fact that ACI effects are visible when *SINR* exceeds 20 dB.

Also, a set of experiments having as results the statistics of lost packet, under the impact of interference in diverse conditions, are presented. Here we must remark that the general model for *ILU* could benefit of much information if statistics are obtained in a programmed sequence of scenarios where the interference is associated (and measured) with its main features/parameters. Then the statistics could be integrated in IDB and data will be used in COMSINP.

For further research it is clear that, for implementing COMSINP, we have to work on the mentioned programmed sequence of scenarios in order to describe interference.

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BIOGRAPHIES

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