An Adaptive Mechanism for Access Control in VANETs

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***Abstract*—VANETs have the ability to transmit various types of information between a vehicle and another, or between a vehicle and a fixed station. However, transmission may be impaired due to long delays, quantity of collisions and signal noise. This is caused, in part, by abrupt changes in the network topology. Thus, in order to maintain the quality and stability of the network, a mechanism is proposed for the vehicle to self-adapt dynamically according to the context. For this purpose, MAC layer parameters must be changed, allowing better control of access to the medium.**

***Keywords*—*VANET; 802.11p; Contention Window; Density; Fuzzy Logic*.**

I. INTRODUCTION

The main goal of VANETs (Vehicular Ad Hoc Networks) is to allow vehicles to exchange information to enable the use of safety support applications such as: emergency warning systems and accident prevention. But, comfort applications are another type of application that will be present in VANETs [1].

The network environment present in VANETs can take on diverse configurations. It can be a sparse network without atmospheric interference, or it can be a dense network on a rainy day in a big city. This second scenario can lead to a strong degradation of network performance. Moreover, this environment can change from sparse to dense or vice-versa. In each case, the network needs to adapt to the environment in order to work properly [2].

Thus, in order to optimize network resources, meet the requirements of different applications and dynamically adapt to network conditions and traffic, we propose a mechanism that has been developed with the support of fuzzy intelligence in order to better control the VANETs and adapt medium access control (MAC).

This work is organized as follows: Section 2 presents related works. In Section 3 the theoretical basis is shown. The architecture is explained in detail in Section 4. Sections 5 and 6 report on the scenario, results and analysis. Future works and conclusion are outlined in the last sections.

II. RELATED WORK

In VANETs, the adaptability of protocols to the environment has been investigated with the goal of not letting a highly changeable scenario degrade network quality.

Shankar *et al.* [3] shows that the rapid changes in the quality of connections and the rapid mobility of vehicles cause the sub-utilization of network resources when the default network settings are static. Thus, a scheme is proposed for adapting the transmission rate to better utilize network capacity. For this adaptation, the proposed scheme evaluates some information from GPS (Global Positioning System) and some metrics of network performance. However, in this paper, density was not used as a context parameter.

Artimy *et al.* [4], consider density as an important parameter in their work. The rapid change in topology, due to traffic jams, is shown to disturb the homogenous distribution of vehicles on the road. Dynamic transmission power has been proposed as a manner to maintain network connectivity and minimize the adverse effects of unregulated power.

The contention window (CW) also plays an important role in adjusting the network. In the paper of Wang *et al.* [5], the contention window (CW) of a vehicle is adapted according to the neighborhood density of a stationary unit (RSU). Thus, the adaptation algorithm is centered on the RSU.

Another aspect that has received attention in the scientific community is Quality of Service (QoS), because it is very vulnerable to the environment. Adler *et al.* [6] proposes a system to prioritize messages based on context and content. On this basis, a function of relevance is calculated for each message, and each message will have different CWs (Contention Window).

Protocol scalability also gains with the adaptation. Mertens *et al.* [7] states that, in broadcast scenarios, there are significant problems with scalability due to the flood of messages among the cars. In this adaptation, the CW is modified according to the PER (Packet Error Rate), and the data transmission rate is changed according to the degree of congestion of the channels.

It is important to quote the all the approaches proposed above for VANETs MAC layer address changes have a reactive aspect, i.e., they wait for the channel to become congested or for the level of the PER to increase. These solutions do not prevent large amounts of packets from being discarded while waiting for the network to adapt through some mechanism in order to change that scenario. Another unpromising approach is to individually set the importance of each message through different CWs for each one. This creates a large overhead and processing time.

In order to overcome this problem, this article proposes a mechanism of network adaptation to the traffic scenario in

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VANETs in order to improve the quality of transmission and reception of packets. Traffic density information are taken into account as a parameter to be used by a traffic based fuzzy logic analyzer and, thereafter, the MAC layer parameters can be change dynamically. The proposed architecture consists of two main modules: a contextual information captor and an information analyzer. It is important to note that the changes are predictive, since they do not have to wait for any degradation of the network to make any adjustments.

III. Theoretical Foundation

A. Density

In different VANETs scenarios, speed fluctuation, traffic signs, the road model and other factors that are described in traffic engineering contribute significantly to changes in network density, disrupting homogeneous node distribution. These abrupt and frequent changes create a highly dynamic topology and can cause degradation in network performance if the protocols are not designed to handle such situations.

Panichpapiboon *et al.* [8] and Yousefi *et al.* [9] show studies on network connectivity and attest to the importance of density for the connection. Among other things, they emphasize that density affects network connectivity proportionally, i.e., the higher the density, the greater the connectivity. The impact of network connectivity can be felt in different ways. Tonguz *et al.* [10] shows that higher the density, the higher the packet loss rate due to problems of contention and collisions. Moreover, reducing the density increases idle time spent in transmission / reception of a packet and for a sparse network there will be more retransmissions as observed in Shankar *et al.* [3] and was observed that increasing the density increases the rate of penetration, i.e., the number of nodes that can be reached by the message [8] [10].

Therefore, density can be considered a very important feature for VANETs. A protocol project should consider its influence on the quality of transmissions to allow continuous and reliable exchange of information between vehicles.

B. Backoff Time

Backoff time is a time value that determines the time of transmission. It is calculated by a random value, chosen based on the contention window, multiplied by a time slot [11]. Higher priority will be assigned to the least amount of backoff time. The backoff value has been taken into account in the fuzzy system calculations and in the evaluations made in this work.

Besides the density, Natkaniec *et al.* [12] estimated that the contention window is crucial to reduce the probability of collision and increase network throughput. Bianchi [13] presents a more detailed study of this feature by showing that the saturation throughput, limit reached by the throughput in overcrowded conditions, is strongly dependent on the contention window and that its optimal value choice depends on the number of network nodes.

C. Fuzzy Logic

The probability theory can be used to formally represent information in stochastic decision environments. It represents the uncertainty associated with the randomness of events. The theory of fuzzy sets, in turn, seeks to represent the uncertainty associated with vague, inaccurate or independently unrelated information. These sets were developed by Lotfi Zadeh and initially published in 1965 [14].

Given that present day complex networks are dynamic, i.e., there is great uncertainty associated with the input traffic and other environmental parameters, that they are subject to unexpected overloads, failures and disturbances, and that they defy accurate analytical modeling, fuzzy logic appears to be a promising approach to address key aspects of networks. The ability to model networks in the continuum mathematics of fuzzy sets rather than with traditional discrete values, coupled with extensive simulation, offers a reasonable compromise between rigorous analytical modeling and purely qualitative simulation [15].

D. Dedicated Short Range Communications (DSRC)

Dedicated Short Range Communications (DSRC) is the standardization of a spectrum band in the United States [2]. In 1999, the Federal Communication Commission of the United States allocated 75MHz of the DSRC spectrum in 5.9 GHz to be used exclusively for vehicle-to-vehicle or vehicle-to-infrastructure communications.

The DSRC spectrum is divided into 7 channels of 10 MHz. Channel 178 is the control channel (CCH), which is exclusive for security communications. The two side channels are reserved for special uses. Others are service channels (SCH) available for use in security and comfort communications.

WAVE architecture (Wireless Access in the Vehicular Environment) uses standard DSRC.

E. Wireless Access in the Vehicular Environment

In 2004, the IEEE began the standardization of communications in vehicular networks, called WAVE architecture (figure 1) which is defined currently in five documents: IEEE P1609.1, IEEE P1609.2, IEEE P1609.3, IEEE P1609.4, IEEE 802.11p.

IEEE 802.11p defines the physical layer and medium access control (MAC) for vehicular networks. This proposed standard specifies the extensions to IEEE 802.11 that are necessary to provide wireless communications in a vehicular environment.

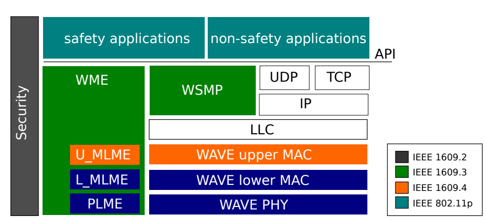

Fig. 1. WAVE Architecture

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F. Wave Short Message Protocol (WSMP)

According to Figure 1, WSMP (WAVE Short Message Protocol) is an alternative to the use of TCP / UDP, and IPv6 in WAVE environments. The justification of an alternative network service is the greater efficiency in the WAVE environment, where it is expected that most applications require very low latency and are non-connection-oriented. Many broadcast applications use WSMP to minimize the size of messages and reduce the delay for critical security messages [16] [17].

IV. Proposed Mechanism

In this paper, we propose a mechanism for backoff time self-adaptation in VANETs, as illustrated in Figure 2. The Captor module is responsible for obtaining density information that is passed to the Analyzer. The Analyzer also receives information about the value of the random backoff time chosen. from the 802.11p MAC layer protocol. Using the value received, the analyzer will check if this value is conforming to the current situation of vehicular traffic. Without this mechanism, in a very dense scenario, the value of the backoff time chosen may be very small. In this case, when there are several transmitting cars, there may be a higher probability of collisions, losses, etc.

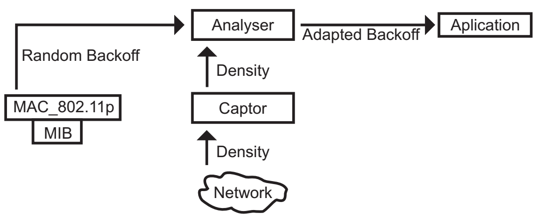

Fig. 2. Proposed Mechanism

One advantage of this mechanism is the use of prediction rather than reaction. There is no need to wait for the degradation of the service network to do something about it. In reactive systems, during the time taken to measure the degree of congestion in a channel, the amount of PER or the amount of collisions, only to adapt the network parameters, there may be more collisions and more packet loss. Using density as a context descriptor and performing dynamic update of parameters, there is no need to let the network conditions get worse and then make an adjustment. Before there is a decline in transmission quality, the network can already adapt and thus maintain its stability.

A. Captor

Literature mentions two ways to obtain the density for a particular vehicle. The density can be disseminated among the vehicles through beacon messages [3] [18]. Each vehicle delivers its speed and position to other vehicles. Thus, a vehicle can count how many neighbors are in its range and calculate its own density, and it may also spread its own density. Another way is mentioned in Artimy *et al.* [4]. The density is estimated based on the number and length of stops the vehicle makes. The more the car stops, and the longer it stands there, the greater the density.

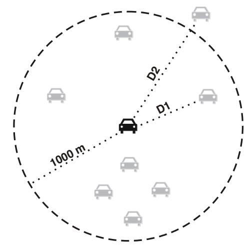

Fig. 3. Density by Transmission Range

As the focus of this paper is not to find the best way to get the density of a vehicle for this task we used a native function of the simulator (see Section 5). The function calculates the distance between vehicles in a given transmission range. As the distance from a node to a given vehicle diminishes in relationship to the transmission range of that vehicle, the value of the density is increased. In Figure 3, the central vehicle has a density of 7. The vehicle is at a distance D1 is being recorded for that value, but the car at a distance D2 is not, because D2 is greater than the central vehicle transmission range.

The context information need not be calculated for each transmission [3]. Considering that in scenarios of high mobility (vehicular speeds equal to 105km / h) in 100ms a vehicle has moved less than 3m. As the density changes little in that interval, we used 1 second periods to capture information about density.

B. Analyzer

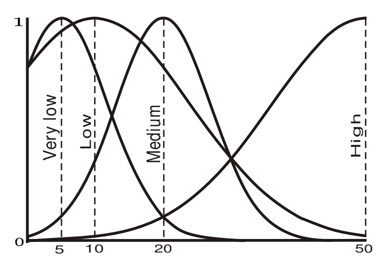

Fig. 4. Fuzzy Sets for Density

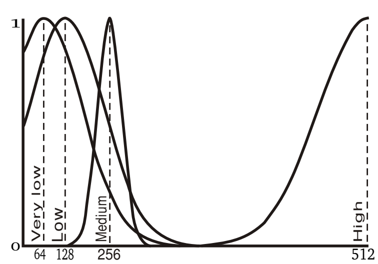

Fig. 5. Fuzzy Sets for Backoff Value

The Analyzer receives the following information: the density, from the Captor module, and the backoff time based on the MIB contention window range defined by the 802.11p protocol. The purpose of this module is to ensure that the backoff time will be adjusted in accordance with the traffic scenario.

A fuzzy system is used to describe the values. Thus, a very dense network should increase its backoff time to attempt a reduction in the amount of packet collisions. A sparse network should reduce the backoff time in order not to underutilize network resources.

Figure 4 shows the fuzzy sets for density classification based on Wisitpongphan *et al.* [19].

Figure 5 shows the fuzzy sets that return the optimal backoff time based on Wang *et al.* [5].

The fuzzy system calculates a new backoff value based on vehicle density in order to optimize access to the medium. If the density is low, the fuzzy system returns a small backoff value and close to the optimum value [5] in order not to underutilize the network. On the other hand, if the network is dense, the returned backoff value is great and near to optimal value, enough to provide a good cost-benefit relationship between throughput and collisions or loss.

A new backoff value is generated only when the channel is busy, in other words, when the node is not transmitting, although the density values are sent every second to the Analyzer.

However, to avoid all vehicles from calculating the same backoff time, the adjusted value is added to the little random value generated by the 802.11p MAC layer protocol, which is passed to the analyzer.

V. SCENARIO

The simulator used for the experiments was the NCTUns 6.0 [20]. The NCTUns has a complete implementation of IEEE 1609 and 802.11p standards. It is opensource and is allowed to add on new modules and agents. However, the simulator does not support more than 4096 nodes in a simple simulation.

The scenario used was a stretch of highway 6km long. All vehicles have OBUs (On Board Units) and there is no RSU (Road Side Unit). The propagation model used was the Two Ray Ground [21]. Vehicular traffic was generated according to a Poisson process. Three environments were tested in this scenario: a sparse density environment with 35 vehicles, an average density environment with 50 vehicles, and a highly dense environment with 200 vehicles.

Each vehicle has a transmission range of 1km and its mobility is controlled automatically. This control is carried out by an agent attached to the simulator called *CarAgent*. The vehicles have a maximum speed of 130km/h, maximum acceleration of $3m/s^2$ and maximum deceleration of $5m/s^2$. All vehicles have 1.5 meter omnidirectional antennas.

Traffic is generated through an agent called WSM which simulates WSMP, but without retransmissions. Every 100ms, a broadcast Wave Short Message is transmitted. For experiments, we used an application that works with WSMP. Each WSMP message has a length of 1458 bytes and uses the control channel (178).

VI. RESULTS AND ANALYSIS

The aim of the experiments is to compare the adaptive approach with the non-adaptive approach, i.e., to compare the dynamic approach with the 802.11p standard. According to Bilstrup *et al.* [11], IEEE 802.11p uses the following to calculate backoff: (i) it chooses a uniform distribution integer between 0 and $CWmin$ (minimum contention window for a given class), (ii) it multiplies the choosen integer by a certain time slot at the physical layer, (iii) it decreases the backoff only when the channel is free, (iv) when backoff reaches zero, it transmits immediately. When a problem is detected in the transmission, the value of the contention window is doubled. Upon successful transmission, the contention window value returns to the initial value. However, in *broadcast* situations, there is no way to know if there was problem in the transmission because there is no confirmation. Thus, the contention window value is always CWmin. Thus, there is a higher probability of calculating the same backoff time and transmitting data at the same time, causing a greater number of collisions [22].

To analyze the network situation, we used three metrics: number of packets received per second (BRX), amount of packet loss (DROP) and percentage of success (SUC). The amount of packets lost is the sum of errors caused by collisions and discards. The success rate is the number of packets received divided by the number of packets that should have been successfully received if no losses occurred. Thus, $SUC = BRX/(BRX + DROP)$.

In the drop chart and packet loss chart, these values grow up to a certain point, and then they decrease. This happens because the densities calculated for each vehicle are very low in the first and the last moments. The cars enter and exit by the Poisson process. These metrics will be highest when all vehicles are present on the track, when it has the highest density.

In figures 6, 7 and 8, with the adaptive approach, packet loss is less than with the standard approach. This happens because the vehicles use a backoff value close to optimum, reducing the likelihood of the medium being used at the same time.

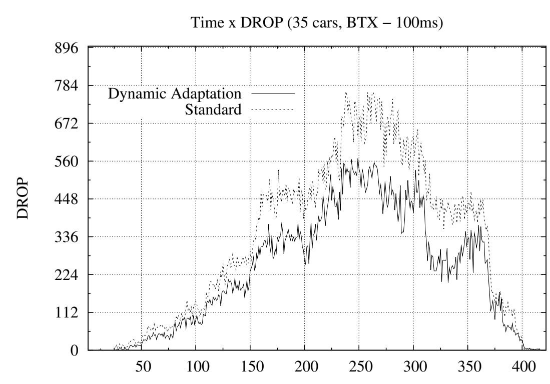

Fig. 6. Quantity of overall packet losses for sparse scenarios

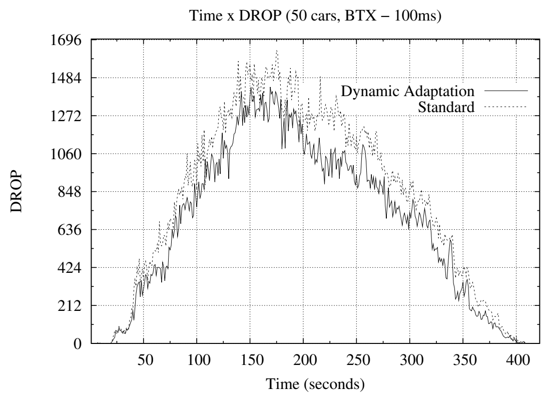

Fig. 7. Quantity of overall packet losses for medium scenarios

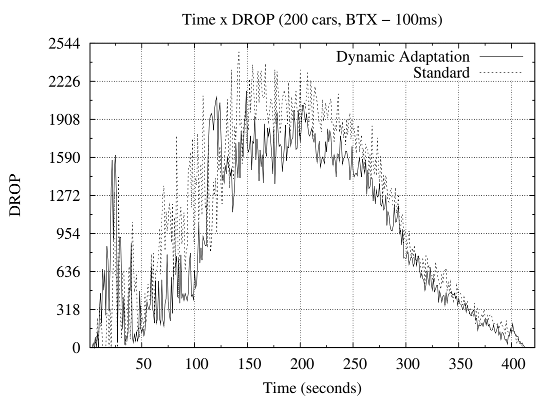

Fig. 8. Quantity of overall packet losses for dense scenarios

In figures 9, 10 and 11 with the adaptive approach, receptions per second is greater than with the standard approach, i.e., a greater number of neighboring vehicles is reported from a single message from a transmitting node. Since there is no retransmission, this metric provides a view of the rate of packet delivery in the neighborhood of a node. Moreover, backoff time is close to the optimum value. This way, the medium is better shared.

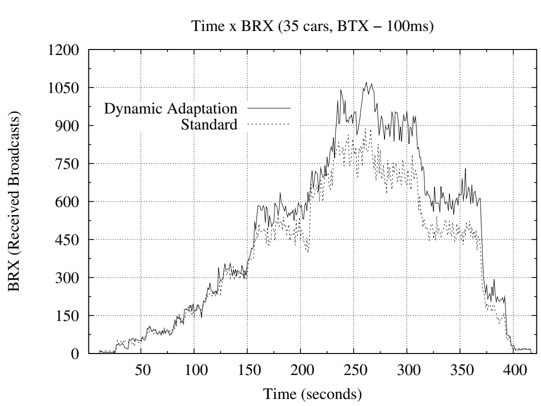

Fig. 9. Overall quantity of received packets per second for sparse scenarios.

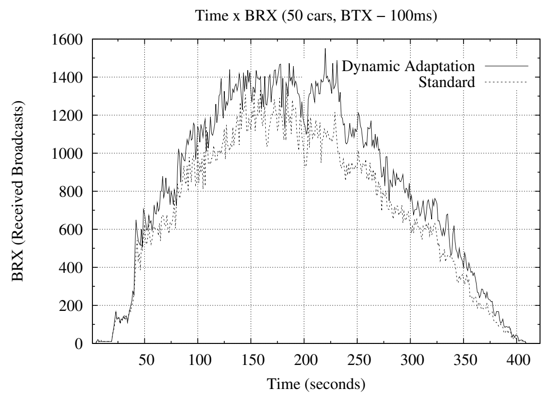

Fig. 10. Overall quantity of received packets per second for medium scenarios.

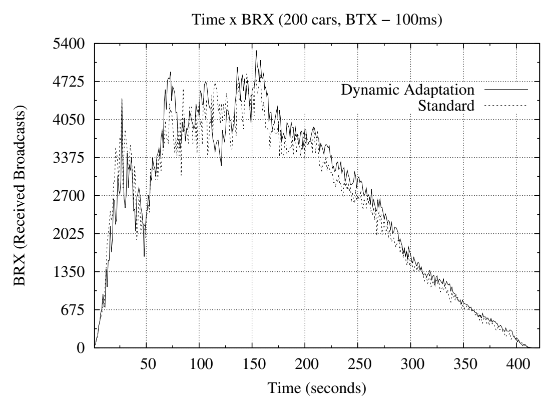

Fig. 11. Overall quantity of received packets per second for dense scenarios.

In figures 12, 13 and 14 with the adaptive approach, there is an improvement in the percentage of success because this approach received more packets per second with less losses. This means that, considering the total number of packets that should be received, the adaptive approach was more successful than the standard approach.

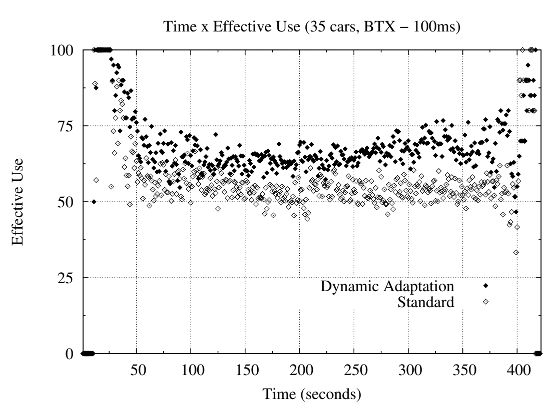

Fig. 12. Percentage of success for sparse scenarios

Therefore, the adaptive approach provides better network quality by adjusting backoff time and optimizing sharing of

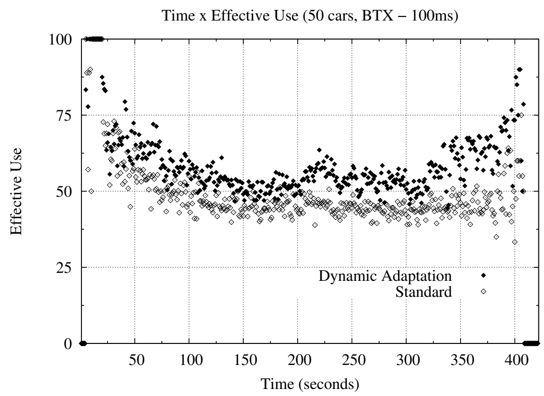

Fig. 13. Percentage of success for medium scenarios

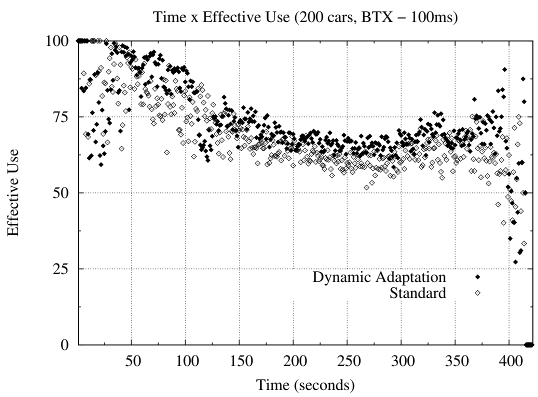

Fig. 14. Percentage of success for dense scenarios

the wireless medium. Thus, with the adaptive approach, we obtained better performance than with the standard approach (802.11p).

VII. Conclusion and Future Work

This work, proposed a mechanism for context adaptation to better control network use. Density was used as a context descriptor, and the backoff time as a parameter to be changed dynamically in each vehicle to handle its access to medium.

The adaptive approach has proven effective for all scenario types: sparse, medium and dense. Collisions and drops decreased. Useful network throughput was increased since the amount of packets received per second increased in all scenarios evaluated.

In the future, we intend to work with other network parameters, such as data rate, transmission power, AIFS, etc. Other context parameters as speed, acceleration, connectivity, signal strength, BER, etc can also be verified. In addition, applications that use TCP, UDP or RTP will be tested. Other ways to obtain density will also be analyzed.

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