# Packet Relaying Strategies for Polling Based Ad-Hoc WLANs

A.Giovanardi, G. Mazzini

DI
University of Ferrara
Italy
(a.giovanardi|g.mazzini)@chaos.cc
http://www.chaos.cc

*Abstract:* – By considering a stand-alone WLAN system, some possible packet relaying strategies are proposed and compared. These strategies are based on the possibility of using a terminal in the WLAN as a relay point, following three different approaches, so that the path between source and final target is realized by means of hops on intermediate stations. The medium access protocol is a polling and the control is hold throughout a token. The performance evaluation is made through simulations, in which are taken into account some simple models for terminal mobility, traffic generation, propagation channel, modulation and retransmissions. The simulations have the purpose of showing the impact of the system parameters and making a comparison between the strategies introduced.

*Key-Words:*–Computer Networks/Protocols, Queuing Theory and Communications/Traffic Problems

## 1 Introduction

Due to the low-cost of portable computers, it is very interesting to investigate the possibility of building an ad-hoc network between stations inside a meeting room. To achieve a fast and user transparent installation of the LAN a possible choice is a wireless access, based on radio or infrared technologies (WLAN). The recently introduced possibility of using the 2.4GHz ISM band without license makes the choice of the radio access very interesting for its feasibility and low-cost impact.

An ad-hoc network (also called peer-to-peer network) is based on stations that all have the same functions and that attempt to make connections directly, i.e. without help of a particular entity, called HUB, typical of a structured WLAN.

In this paper the access method is based on a polling scheme, i.e. the medium access is gained from a station by means of a token passing [1] [2] [3]. Two categories of problems should be investigated in a polling WLAN: the packet relaying methodology and the stations management (insertion, deletion, token loss etc.). The paper is addressed to the former problem, leaving the latter one to further investigations.

In literature the packet relaying methods are investigated into various contests and scenarios, ranging from the cellular mobile networks, to the indoor WLANs and the distributed microprocessor systems [4] [5] [6] [7] [8].

In this paper three different packet relaying strategies are proposed and analyzed by giving the relative system performance and comparison, taking into account terminal mobility, traffic generation, propagation channel, modulation and retransmissions.

Let us introduce these packet relaying strategies:

- **MULTIHOP:** let us suppose that each station can estimate the performance of each possible radio link. Let us assume having implemented a procedure able to forward this information to all other stations, so that each station has a total knowledge of links reliability. Furthermore, let us assume that the channel is quite stationary, so that the link information exchange can be considered very low and the overhead introduced by this information forward can be neglected in the performance evaluation. In order to minimize the delivery time, a station, for each packet, is able to compute the best path to forward it at the target, i.e. the path which includes links between stations more reliable as possible. Thus, the packet path is realized by using other stations with relay functions by carrying out an unspecified number of hops, depending on the reliability and the packet length. The token is passed between the stations by following a rotation scheme that is decided at the network start-up and for each new station entry in the WLAN. The token is passed by means of a MULTIHOP strategy as the generic packet.

- **BIHOP:** let us suppose we can select a station placed in a particular space position that gives the best possible reliability for direct links with all other stations. This fortunate entity can be selected through an opportune signaling procedure between the stations, as for the MULTIHOP case. This particular station is chosen in order to relay the packets from the source to the target, by building a dual hop path, as a HUB should make. So, the stations simply forward packets to the pseudo-HUB, which directly delivers these packets to the target. The pseudo-HUB position is renegotiated when new reliability functions are available. The pseudo-HUB also provides the token passing between all other stations.

- **LOWHOP:** let us suppose we organize the WLAN as reported in the BIHOP scheme and let us assume that when a station holds the token decides if it is better to send the packet directly to the target or to the pseudo-HUB which performs as relay agent. In this way the number of hops are one or two, respectively. As far as the token passing is concerning, the same strategy of the BIHOP case is implemented.

Since a particular channel condition can impose very long times to send the packets or even prevent their delivery by stopping all other network activities, we have assumed dropping all packets over those links characterized by inadequate reliability functions.

In order to evaluate the better packet relaying strategy, in the following a comparison is made by means of a merit factor, based on the average access time, $T_{acc}$, i.e. the average time from a packet creation to the final delivery, and by means of the fraction of the packet that are dropped, $\alpha$.

The paper is organized as follows: in section 2 a general overview on the network assumptions and model is reported; in section 3 the algorithms relative to the proposed relaying strategies are described in detail; in section 4 some numerical results are shown; finally, in section 5 the conclusions are drawn.

# 2 Network Model

The network model is composed of the following topics: terminal location and mobility, traffic generation, propagation channel, modulation scheme and retransmission strategy. A brief discussion of these topics follows.

## 2.1 Station Location and Mobility

Let us consider an indoor environment shaped as a squared room of dimension $D$ and $N$ stations. The stations are randomly distributed on the limited plane and the configurations are refreshed every $REF$ seconds. These successive generations of stations positions may be considered both to simulate a low speed mobility and to average on different starting situations. In order to respect the stationarity channel hypothesis, the refresh rate must be very low with respect to the transmission rate, $C$, i.e. $1/REF \ll C$. In order to keep the model complexity low, no correlation between successive stations positions is considered.

## 2.2 Traffic Generation

The network is assumed to be stand-alone or closed, i.e. no interconnections with other networks are present. The stations are assumed to have an uniform, equal, activity. The traffic generation is obtained by assuming the aggregation of stations as a succession of ON and OFF states, so that it can be modeled through an ON-OFF Markov chain [9]. The time spent in each state, $T_{ON}$ and $T_{OFF}$, is exponentially distributed due to memoryless behavior. The averaged times $\overline{T}_{ON}$ and $\overline{T}_{OFF}$, characteristic of the exponential distribution, can be set by specifying two synthetic and measurable parameters: the average number of bits present into a packet, $\overline{b}$, and the network throughput, $S$. The relationship between these two couple of parameters are:

$$\overline{T}_{ON} = \frac{\overline{b}}{C} \qquad \overline{T}_{OFF} = \frac{\overline{b}}{C}\frac{1-S}{S}$$

In order to generate packets for the simulation process, the vector $(T_s, b, So, Ta)$ should be created, where $T_s$ is the packet creation time, given by the transition from the OFF to the ON state, and computed by accumulating the $T_{ON} + T_{OFF}$ times; $b = C\ T_{ON}$ is the number of bits present into the packet; $So$ and $Ta$ are the source and the target stations, respectively, randomly generated with a uniform distribution in the range $1, \ldots, N$ with the constraint $So \neq Ta$.

## 2.3 Propagation Channel

Some different approaches can be used to model an indoor environment. The more frequently used consists of simulating the propagation channel by means of a ray-tracing technique and obtaining for each possible couple of space coordinates the impulsive response. In this work let us consider the information rate sufficiently low with respect to the fading rate, so that the channel can be considered not selective and the use of the ray-tracing can be avoided. On the other hand, if the actual channel is selective it is also possible to consider an equivalent flat channel when an equalization or a multipath robustness modulation is adopted. Bearing this in mind, let $d_{i,j}$ be the distance between the $i$-th and the $j$-th station computed when the position on the plane is given, then the signal to noise ratio at the receiver is:

$$\rho_{i,j}[dB] = \gamma[dB] - 10\beta \log(d_{i,j})$$

where $\gamma$ considers the transmitted power, the receiver noise figure and the presence of interference due to other WLANs or other devices; $\beta$ represents the power decay law with the distance.

Another characteristic parameter of the channel is the propagation delay, $\tau_{i,j}$, which is directly computed by considering the light speed $c$ as : $\tau_{i,j} = d_{i,j}/c$.

The couples $(\rho_{i,j}, \tau_{i,j})$, evaluated for each station when the terminals positions are fixed, fully characterize each link. They can also be substituted with measurements or ray-tracing simulations when available, without changing other part of the methodology illustrated here.

### 2.4 Modulation Scheme

In order to achieve a high information speed, by using millimeter waves, the literature gives some proposals of very complex modulation schemes [2] [10]. Let us note that the first problem of an ad-hoc network is the inter-working and that the number of stations present in the room is usually quite low. These considerations give a low capacity request, so we propose using a simple BPSK modulation, which is low-cost and robustness.

The channel parameters couples, $(\rho_{i,j}, \tau_{i,j})$, become performance couples, $(P_{i,j}, \tau_{i,j})$, where $P_{i,j}$ is the bit error probability computed by means of the simple formula:

$$P_{i,j} = \frac{1}{2}\text{erfc}\sqrt{\rho_{i,j}} \quad (1)$$

### 2.5 Retransmission strategy

When the basic traffic is a data traffic, it is very important to deliver the information without errors. The proposed system attempts performing the classical functions of the layer two in the ISO-OSI reference model, so it must give error-free frames to the upper layers, where a frame can be a packet or a token. This is possible by adopting a simple stop-and-wait ARQ scheme. By considering $n_{i,j}(x)$ the number of total transmissions necessary to deliver a frame of length $x$ correctly, the corresponding time is [11]:

$$\begin{aligned} T_{i,j}(x) &= n_{i,j}(x)\left[\frac{x+A}{C} + 2\tau_{i,j}\right] \\ n_{i,j}(x) &= \frac{1}{(1-P_{i,j})^x} \end{aligned}$$

where a strict timeout is considered and $A$ represents the length of the ACK, assumed in the following equal to the length of the token. With this assumption, when the frame is a token we have $x = A$, while if the frame is a packet $x = b$. Furthermore, for each packet the probability that $A < b$ is assumed to be very high, so that on average the ACK and the token lengths are smaller than the packet one.

As previously observed, there may exist a particular channel reliability and packet length combination that can involve a very long time for the correct packet delivery. This event stops all other network activities. Since the stations can presumptively computed this condition, they can prevent the block by dropping the transmission of all packets which have a number of transmissions exceeding a given threshold $n_t$, i.e. $n_{i,j}(b) > n_t$. This drop possibility is not considered for the signaling packets, i.e. ACKs and tokens. This is possible in virtue of the previously discussed smaller length of these frames with respect to that of a generic packet, which correspond to an higher probability of their fast delivery. The dropped packets will be rescheduled by the upper layers protocols with an opportune back-off time. If this back-off is sufficiently high, the channel may be changed and the packets could be correctly delivered, otherwise, the upper layers protocols should introduce an opportune fragmentation factor, in order to reduce, on average, $b$ and then $n_{i,j}(b)$.

## 3 Relaying Strategies Characterization

In this section, noting that the access methodology is a polling based on a token passing, the relaying strategies presented in section 1, are reviewed and detailed described. The target is to evaluate the performance of each methodology and to make a comparison.

The evaluation is made by assuming that all stations have complete knowledge of the links reliability by means of the couples $(P_{i,j}, \tau_{i,j})$. The estimation of these couples is performed through the following procedure:

- each station (source) sends a short test packet to all other terminals (targets) for which it has not yet collected link information;
- each target terminal reply to the source station as soon as possible;
- the source station evaluates the propagation delays by halving the measured round-trip time;
- the source station measures the echo received powers and computes the bit error probabilities

by means of the formula (1) by considering the measured powers and its noise figure;

- the source station floods the evaluated parameters to each target terminal for which it has collected link information.

This procedure is made by all the WLAN stations in each refresh time, so that at the end they have a complete knowledge of the reliability function relative to all possible links, due to the symmetry $P_{i,j} = P_{j,i}$ and $\tau_{i,j} = \tau_{j,i}$.

The final performance will be reported in term of the service availability, a merit factor which represents the probability that the access time is below a given threshold $T_{th}$, i.e.:

$$\text{service availability} = \text{Prob}[T_{acc} < T_{th}]$$

and by means of the fraction of the dropped packets, $\alpha$.

## 3.1 MULTIHOP Characterization

In the MULTIHOP case, the generic station must decide the best path for the packets delivery in terms of succession of hops. For this purpose we use a modified Dijkstra algorithm [12]. Let $l_{i,j}(x)$ be the time to deliver a frame of length $x$ from the $i$-th to the $j$-th station. If the frame is a packet ($x = b$), we have:

$$l_{i,j}(b) = \begin{cases} \infty & \text{if } n_{i,j}(b) > n_t \\ T_{i,j}(b) & \text{otherwise} \end{cases}$$

where $n_t$ is the drop threshold.

If the frame is a token or an ACK ($x = A$), it results:

$$l_{i,j}(A) = T_{i,j}(A)$$

Let $D_v(x)$ be the cost function relative to the link between the $So$-th and the $v$-th generic station and let $Q_{So,Ta}(x)$ be the time to deliver the frame to the target by following the best path. Then, the algorithm is:

**1)** $\mathcal{F} = \{So\}$ and $D_v(x) = l_{So,v}(x)\ \forall v \notin \mathcal{F}$;

**2)** $w \notin \mathcal{F} | \forall z \notin \mathcal{F}, w \neq z, D_w(x) \leq D_z(x)$;

**3)** if $w = Ta$ or $D_w(x) = \infty$ then $Q_{So,Ta}(x) = D_w(x)$ and exit;

**4)** $\mathcal{F} = \mathcal{F} \cup \{w\}$;

**5)** $\forall z \notin \mathcal{F}\ D_z(x) = \min[D_z(x), D_w(x) + l_{wz}(x)]$;

**6)** goto step 2;

The access is realized by passing the token between the stations by using this algorithm in order to minimize the hops present in the links. The time to pass the token from the $i$-th station to the next one, $1 + (i + 1) \bmod N$, results to be $Q_{i,1+(i+1) \bmod N}(A)$ for $i = 1, \ldots, N$.

When there is a packet creation, characterized by the $(T_s, b, So, Ta)$ vector, the $So$ station must wait for the token, then it can deliver the packet if $Q_{So,Ta}(b) < \infty$, otherwise drops it.

For all packets delivered with this scheme a time $Q_{So,Ta}(b) + Q_{Ta,So}(A)$ is considered, where the latter term represents the time to return an explicit ACK from the target to the source by passing all the hops into the path. This ACK has been included, although each link which compose the path is managed with an ARQ strategy, due to the need to inform the original source when the packet has been delivered so that the source can pass to the next action.

## 3.2 BIHOP Characterization

In the BIHOP case the first problem is the selection of the pseudo-HUB with relay functions. Even if in literature some possible algorithms for this selection are present [13], by considering that each station knows the reliability function of each link, we propose making this selection presumptively by using the bit error probability as cost function. With this regard, let us note that as the bit error probability increases, the number of transmissions increases. This choice does not consider the propagation delay impact, which should be a secondary effect with respect to the bit error probability, and not take into account the packet length due to its random nature.

The algorithm searches for the station which minimizes the maximum link error probability relative to all other WLAN stations:

**1)** $P_i = \max_{j \neq i}[P_{i,j}]$

**2)** $h | \forall z, z \neq h, P_h < P_z$

then $h$ represents the selected pseudo-HUB. The pseudo-HUB also performs control passing function, i.e. passes the token to the $j$-th station with time $T_{h,j}(A)$, $j \neq h$, and receives the token from it with time $T_{j,h}(A)$, $j \neq h$. For each loop the pseudo-HUB holds the token for its transmissions one time, like all other stations, so that no particular privileges are reserved for it.

When a station holds the token, it tries to deliver the queued packets, characterized by the $(T_s, b, So, Ta)$ vectors, by using the pseudo-HUB as relay. As a first step it checks the possibility of packet delivery by verifying if $n_{So,h}(b) < n_t$ and $n_{h,Ta}(b) < n_t$. If these conditions are not verified the packet is dropped. For all packets sent a resource occupancy time $T_{So,h}(b) + T_{h,Ta}(b) + T_{Ta,h}(A) + T_{h,So}(A)$ is considered, where the two latter terms represent the times need to return an explicit ACK from the final target to the original source, as in the MULTIHOP case.

Regarding the packets generated in the pseudo-HUB and addressed to a station $Ta$ or generated in a $So$ station and addressed to the pseudo-HUB, they are only delivered if $n_{h,Ta}(b) < n_t$ or $n_{So,h}(b) < n_t$, otherwise they are dropped. In this cases the delivery times are $T_{h,Ta}(b)$ and $T_{So,h}(b)$, respectively.

### 3.3 LOWHOP Characterization

In the LOWHOP case it is also necessary to select a pseudo-HUB. Let us consider the same selection procedure described for the BIHOP scheme and let us use the same token distribution strategy. In this system the novelty is the decision, taken by the generic station, whether to send the packet with a direct delivery to the target or via the pseudo-HUB, as in the BIHOP system.

The station which holds the token first checks the availability of the links with the two conditions: $n_{So,Ta}(b) < n_t$ for the direct one, $n_{So,h}(b) < n_t$ and $n_{h,Ta}(b) < n_t$ otherwise.

If none of these conditions are satisfied, the packet is dropped. Only if one of these conditions is satisfied the corresponding path is selected and a time $T_{So,Ta}(b)$ or $T_{So,h}(b)+T_{h,Ta}(b)+T_{Ta,h}(A)+T_{h,So}(A)$ is added to the simulation one, as a function of the path choice. If both conditions are satisfied, the station selects the path with lower delivery time: $\min[T_{So,Ta}(b), T_{So,h}(b) + T_{h,Ta}(b)]$.

If the source station $So$ or the target $Ta$ is the pseudo-HUB, the procedure and the times considered are the same of the BIHOP case.

### 3.4 Access Time

The access time, $T_{acc}$, is given by the difference between the simulation time necessary to deliver the packets to the final target and the packet creation time $T_s$. Let us remember that the access time is defined as the time from the packet creation to its delivery to the target. Adhering to this definition, if an explicit ACK is used to return the control to the source station, its effect must not be considered in the single packet access time evaluation even if it gives contribution in the packets queue time.

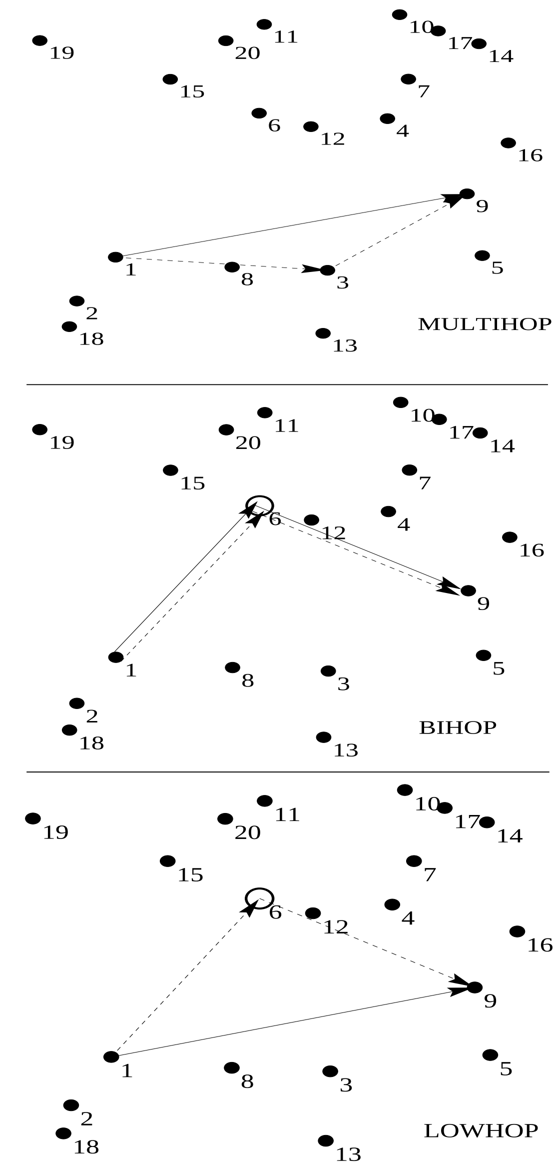


Figure 1: Example of the packet delivery paths for the three relaying schemes, solid line $\gamma = 45$dB, dashed line $\gamma = 40$dB

## 4 Numerical results

The performance of the proposed packet relaying schemes are obtained by means of simulation. All simulations are characterized by: simulation time of 300s, location refresh time $REF = 30$s, drop threshold $n_t = 10$, token and ACK length $A = 56$bit, bit rate $C = 10$Mbs, square room dimension $D = 100$m and power decay factor $\beta = 2$.

As initial result, let us report some flashes of the station topology and of the packet delivery paths selected from the three relaying strategies. Fig. 1 shows an example of the paths for $\gamma = 45$dB and $\gamma = 40$dB. The selected network is composed of $N = 20$ stations where the 1, 9 and 6 ones are the source, the target and the pseudo-HUB (where required), respectively. With the given $\gamma$ values all strategies are able to deliver the packet assumed of $b = 400$bit length. The optimal path is relative to the MULTIHOP system, where one and two hops (via station 3) are present. The BIHOP method is always forced to use the pseudo-HUB. The LOWHOP is able to directly send the packet to the target for $\gamma = 45$dB and by means the pseudo-HUB, as in the BIHOP case, for $\gamma = 40$dB.

A more complex delivery is shown in Fig. 2 where only the MULTIHOP system is considered with $\gamma = 40$dB and $\gamma = 35$dB. The source and the target stations are the number 2 and 10, respectively. The number of requested hops are 3 and 8. Let us note that both the BIHOP and LOWHOP systems, not reported, are not able, for this selected configuration, to deliver the packet, which is dropped.

In order to carry out a performance comparison and to estimate the impact of the assumed parameters, all figures reported in the following show the service availability for the three proposed relaying

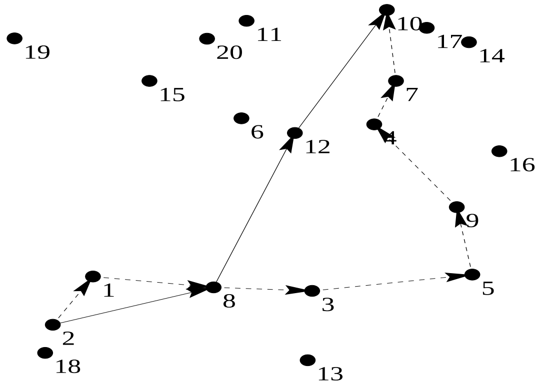


Figure 2: Example of the packet delivery paths for the MULTIHOP case, solid line $\gamma = 40$dB, dashed line $\gamma = 35$dB

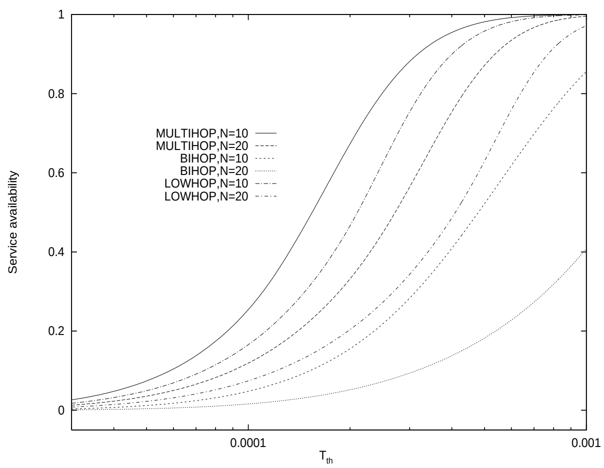


Figure 3: Service availability for $\gamma = 45$dB, $\overline{b} = 400$, $S = 0.3$ and $N = 10, 20$

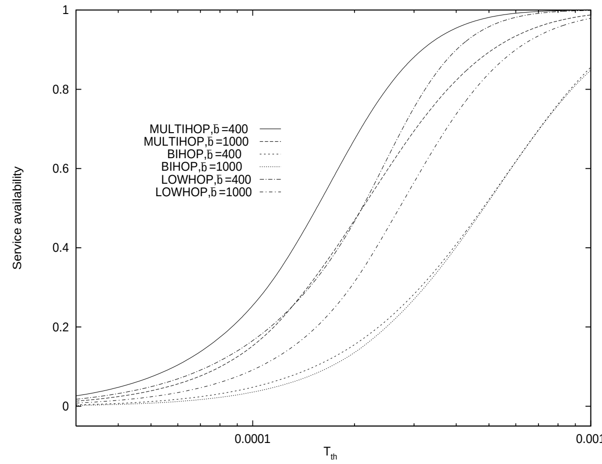


Figure 4: Service availability for $\gamma = 45$dB, $\overline{b} = 400, 1000$, $S = 0.3$ and $N = 10$

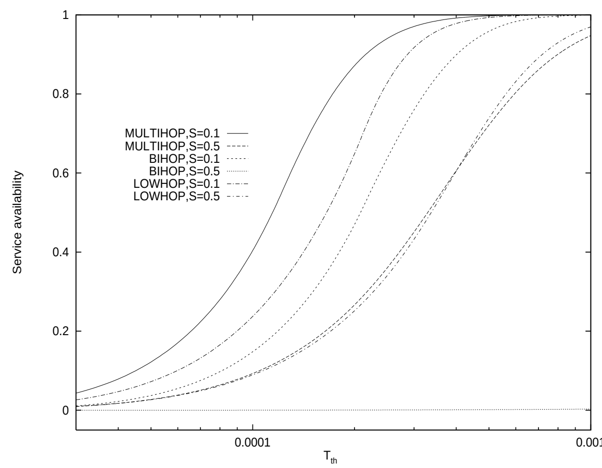


Figure 5: Service availability for $\gamma = 45$dB, $\overline{b} = 400$, $S = 0.1, 0.5$ and $N = 10$

strategies by varying some system values.

In Fig. 3 the comparison is made for $\gamma = 45$dB, $\overline{b} = 400$, $S = 0.3$ by varying the station number $N = 10, 20$. As expected, the MULTIHOP is the best relaying scheme and the LOWHOP outperforms the BIHOP one. By increasing the stations number the performance decreases due to the higher token waiting, which implies a higher queue time. For these configuration parameters, no packets are dropped, then $\alpha = 0$.

The effect of the packet length is investigated in Fig. 4 for $\gamma = 45$dB, $S = 0.3$, $N = 10$ by selecting average bit length $\overline{b} = 400, 1000$. The performance of the three strategies are organized as in Fig. 3 and decrease as the average packet length increases with the exception of the BIHOP scheme that shows the worse performance and the lower sensibility from the packet length. Also for these simulation parameters, no packet drops have been verified.

While in Figs. 3 and 4 the throughput is set to $S = 0.3$ in order to consider a medium traffic condition, in Fig. 5 the low and high traffic behavior effect, $S = 0.1, 0.5$ is drawn for $\gamma = 45$dB, $\overline{b} = 400$ and $N = 10$. When $S = 0.5$ worse performance than in the $S = 0.1$ case are verified due to the higher number of generated packets in each station that implies a greater token waiting and a higher packet queue time when the station holds the control. As far as the throughput increases, the MULTIHOP and LOWHOP performance became very similar, while, in the time access threshold range of interest, the BIHOP shows a null service availability. We have again found $\alpha = 0$.

In Fig. 6 the $\gamma$ parameter is set to 45dB as in the previous investigations and to 40dB, with $\overline{b} = 400$, $S = 0.3$ and $N = 10$. The former setting corresponds to the case approaching an error-free condition, the latter to a difficult channel behavior. A strong performance dependence from $\gamma$ is checked: with $\gamma = 40$dB the LOWHOP scheme performs better than the MULTIHOP one, due to the different token passing mechanism, which, for this $\gamma$ value favors a token passing pseudo-HUB assisted with respect to one attempting to directly transmit the control to the next station. In fact, a difficult chan-

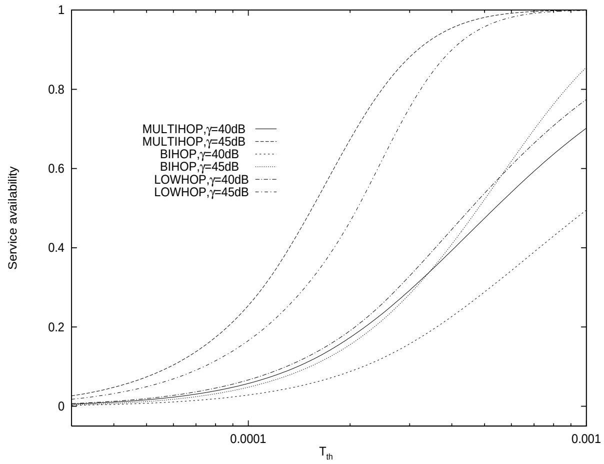


Figure 6: Service availability for $\gamma = 40, 45$dB, $\overline{b} = 400$, $S = 0.3$ and $N = 10$

nel condition implies, for the MULTIHOP, a high number of hops and of transmissions in the token delivery, while, in the LOWHOP case, this delivery is usually performed by means of two hops. On the contrary, with $\gamma = 45$dB the MULTIHOP performs better than the LOWHOP, because the low-error condition gives the possibility of a direct link with the target by means of a single hop and with a low number of transmissions, that implies, for the former case, a token time delivery lesser than the latter one. For all possible $\gamma$ values the MULTIHOP scheme guarantees a packet delivery time lesser than the other ones. The BIHOP results to be the worse system. As far as the fraction of packet dropped is concerned, it results: $\alpha = 0$ with $\gamma = 45$dB for all systems and with $\gamma = 40$dB for the MULTIHOP; $\alpha = 12\%$ and $\alpha = 19\%$ with $\gamma = 40$dB for the LOWHOP and BIHOP cases, respectively. Let us note that, even if for $\gamma = 40$dB the MULTIHOP shows worse service availability with respect to the LOWHOP, it could be a good choice, due to its null fraction of dropped packet.

# 5 Conclusions

In this paper three different packet relaying schemes have been introduced and discussed in detail. The relative performance have been simulated by means of the definition of a simple network model which takes into account the stations location and mobility, the traffic generation, the propagation channel, the modulation scheme and the retransmission strategy. By observing that the relaying structure requires the knowledge of the bit error probability and of the propagation delay for each possible link, a procedure for the estimation of these parameters has been presented.

As far as the performance evaluation and the strategies comparison are concerned, they are drawn by means of the definition of two merit figures with their relative trade-off: the service availability, based on the access time, and the dropped packets fraction.

The simulations confirm that the MULTIHOP is the better packet relaying scheme in all tested conditions, followed by the LOWHOP. The BIHOP scheme has shown a low reliability in all contexts. Let us remark that the BIHOP is the more classical approach for the WLANs, whose are usually organized with a centralized structure, with an HUB situated in a strategic position.

Finally, further efforts should be addressed to investigating a procedure for the signaling and the stations management, and to carry out an analytical characterization of the proposed relaying schemes.

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