Dynamic Retransmission Limit Scheme for Routing in Multi-hop Ad hoc Networks

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ABSTRACT

In paper [2] and [3], we have studied the throughput and stability of forwarding queues in a wireless ad hoc network with random access channel. In this paper, we are focusing to draw benefit from the interaction of the MAC (governed by IEEE 802.11 or slotted aloha) and routing by defining a new cross-layer scheme for routing based on the limit number of retransmission. By adjusting dynamically and judiciously this parameter in a saturated network, we have realized that both stability and average throughput are significantly improved in linear symmetric networks: a gain of 100 % can be reached, while in asymmetric networks, we achieve a better average delay (resp. throughput) for each connection without changing the average throughput (resp. delay). A detailed performance study of our new scheme is presented using analytical and simulation evaluation.

Categories and Subject Descriptors

C.2 [**Computer Systems Organization**]: Computer Communication Networks; C.4 [**Computer Systems Organization**]: Performance of Systems; I.6 [**Computing Methodologies**]: Simulation and Modeling

General Terms

Ad-Hoc Networks, Cross Layer, Performance Evaluation, Routing, Algorithms

1. INTRODUCTION

A multi-hop wireless ad hoc network is a collection of nodes that communicate with each other without any established infrastructure or centralized control. Each of these nodes is a wireless transceiver that transmits and receive at a single frequency band which is common to all the nodes. These nodes can communicate with each other, however, they are limited by their transmitting and receiving capabilities. Therefore, they cannot directly reach all of the nodes in the network as most of the nodes are outside of direct range. In such a scenario, one of the possibilities for the information transmission between two nodes that are not in position to have a direct communication is to use other nodes in the network. To be precise, the source device transmits its information to one of the devices which is within transmission range of the source device. In order to overcome this, the network operates in a multi-hop fashion. Nodes route traffic for each other. Therefore, in a connected ad hoc network, a packet can travel from any source to its destination either directly, or through some set of intermediate packet forwarding nodes.

Clearly, a judicious choice is required to decide on the set of devices to be used to assist in the communication between any two given pair of devices. This is the standard problem of routing in communication networks. The problem of optimal routing has been extensively studied in the context of wire-line networks where usually a shortest path routing algorithm is used: Each link in the network has a weight associated with it and the objective of the routing algorithm is to find a path that achieves the minimum weight between two given nodes. Clearly, the outcome of such an algorithm depends on the assignment of the *weights* associated to each link in the network. In the wire-line context, there are many well-studied criteria to select these weights for links, such as delays. In the context of wireless ad-hoc networks, however, not sufficient attempts have been made to (i) identify the characteristics of the quantities that one would like to associate to a *link* as its weight, and in particular (ii) to understand the resulting network performance and resource utilization. In recent years, an increased effort was consecrated to cross-layer design (in ad hoc) where information is exchanged between different layers. In wireless context where channel conditions and network connectivity impose serious challenges, new cross-layer approaches are needed to optimize performances (various cross-layering approaches are analyzed in [4]).

To study the network performances with the interaction of various parameters from different layers, we consider in this paper the framework of random access mechanism for the wireless channel where the nodes having packets to transmit in their transmit buffers attempt transmissions by delaying the transmission by a random amount of time. This mechanism acts as a way to avoid collisions of transmissions of nearby nodes in the case where nodes can not sense the channel while transmitting (hence, are not aware of other ongoing transmissions). We assume that time is slotted into fixed length time frames. In any slot, a node having a packet to be transmitted to one of its neighboring devices decides with some fixed (possibly node dependent) probability in favor of a transmission attempt. If there is no other transmission

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by the other devices whose transmission can interfere with the node under consideration, the transmission is successful. We assume throughout that there is some mechanism that notifies the sender of success or failure of its transmissions. For example, the sources get the feedback on whether there was zero, one or more transmissions (collision) during the time slot.

At any instant in time, a device may have two kinds of packets to be transmitted: (1) Packets generated by the device itself. This can be sensed data if we are considering a sensor network. (2) Packets from other neighboring devices that need to be *forwarded*. In this paper we consider two separate queues for these two types and do a weighted fair queueing (WFQ) for these two queues. This type of configuration allow us to include in the model the cooperation level which represents the fraction of the traffic forwarded by a node in ad-hoc network.

In [2] and [3], working with the above mentioned system model, we have already studied the impact of routing, channel access rates and weights of the weighted fair queueing on throughput, stability and fairness properties of the network. We obtained important insights into various tradeoffs that can be achieved by varying certain network parameters. The throughput maximization of the multi-hop wireless networks has been extensively studied in [6–8]. However, it is shown that the high throughput in the ad hoc network is achieved at the cost of a high amount of delay. This problem has drown our attention to the relation between the delay characteristic and the throughput.

In this paper, we use a cross layer optimization between MAC and network layer for routing. For a given path between a source and a destination, each intermediate node computes a new maximum number of transmissions based on a specific algorithm. This parameter can be adjusted easily by each node. Using this new routing, we achieve a better average delay (resp. throughput) for each connection without changing the average throughput (resp. delay). In extreme cases, a *reset technique* is introduced to optimize performances.

In most recent literature, the tradeoffs between throughput and delay have been investigate as a key measure of the network performance. Several studies have first focused on wireless network stability and finding the maximum achievable throughput. Among the most studied stability problems are scheduling [15, 16] as well as for the Aloha protocol [1, 14]. Tassiulas and Ephremides [15] obtain a scheduling policy for the nodes that maximizes the stability region. Their approach inherently avoids collisions which allows to maximize the throughput. Radunovic and Le Boudec [5] suggest that considering the total throughput as a performance objective may not be a good objective. Moreover, most of the related studied do not consider the problem of forwarding and each flow is treated similarly (except for Radunovic and Le Boudec [5], Huang and Bensaou [9] or Tassiulas and Sarkar [17]). Our setting is different than the mentioned ones in the following: the number of retransmission is finite, and therefore in our setting, the output and the input rates need not be the same. In recent past year, there has been a considerable effort on trying to increase the performance of wireless ad hoc networks since Gupta and Kumar [7] showed that the capacity of a fixed wireless network decreases as the number of nodes increases. Grossglauser and Tse [6] presented a two-phase packet forwarding technique for mobile ad-hoc networks, utilizing the multiuser diversity, in which a source node transmits a packet to the destination when this destination becomes the closet neighbors of the relay. This scheme was shown to increase the capacity of the MANET, such that it remains constant as the number of users in the MANET increases. Many papers study the tradeoff between throughput and delay. In [12] and [13], the authors achieve a high throughput and low delay in ad-hoc networks. El Gamal et al. [10] analyze the optimal delay-throughput scaling for different wireless network topologies. In the static random network with n nodes, they obtain an optimal tradeoff between throughput and delay. Neely et al. [11] consider the delay-throughput tradeoff only for mobile ad-hoc networks.

The rest of the paper is organized as follows. In section 2, we describe the network model. Then in section 3, we present our new cross-layer dynamic scheme for routing. A detailed evaluation of performance is performed in section 4 to show the efficiency of our new scheme. Finally, we give a brief conclusion.

2. NETWORK MODEL

2.1 Assumptions and definitions

We model the ad hoc wireless network as a set of N nodes deployed arbitrarily in a given area. We assume the following:

- **A one simple channel :** Nodes use the same frequency for transmitting with an omni-directional antennas. A node j receives successfully a packet from a node i if and only if there is no interference at the node j due to another transmission on the same channel i.e. if there is no transmission from any node of the set $N(j) \cup j$ where $N(j)$ is the set of neighbors of node j. We assume that all the nodes in $N(j)$ has j as a neighbor. Note also that a node cannot receive and transmit at the same time.

- **Two types of queues :** two queues are associated with each node. The first one is the forwarded queue, noted by F_i (proper to the node i), which carry all the packets originated from a given source and destined to a given destination. The second is Q_i which carries the proper packets of the node i (in this case $i \equiv s$ where s designates a source node). We assume that each node has an infinite capacity of storage for the two queues. Packets are served with a first in first served fashion. When F_i has a packet to be sent, the node chooses to send it from F_i with a probability f_i. In other terms, it chooses to send from Q_i with probability $1-f_i$. When one of these queues is empty then we choose to send a packet from the none empty one with a probability 1.

- **Saturated network :** each node has always packets to be sent from queue Q_i, whereas F_i can be empty. Consequently, the network is considered saturated and depends on the channel access mechanism.

2.2 Network layer

Network layer handles the two queues Q_i and F_i using the WFQ scheme, as described previously. Also, this layer maintains routing algorithms. So, each node acts as a router, it permits to relay packets originated from a source s to a destination d. It must carries a routing information which permits sending of packets to a destination via a neighbor.

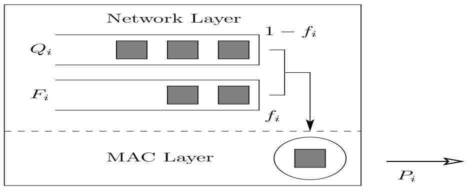

Figure 1: Network layer and MAC layer of node i

In this paper, we assume that nodes form a static network where routes between any source s and destination d are invariant in the saturated network case. Proactive routing protocols as OLSR (Optimized Link State Routing) construct and maintain a routing table that carry routes to all nodes on the network. These kind of protocols corresponds well with our model. Note that the set of nodes between a node s and d is designated by $R_{s,d}$.

2.3 MAC layer

We assume a channel access mechanism only based on a probability to access the network i.e. when a node i has a packet to transmit from the queue Q_i or F_i, it accesses the channel with a probability P_i. For example, in IEEE 802.11 DCF, the transmission probability or attempt probability is given by [18]

$$P = \frac{2(1-2P_c)}{(1-2P_c)(CW_{min}+1)+P_cCW_{min}(1-(2P_c)^m)},$$

where P_c is the conditional collision probability given that a transmission attempt is made, and $m = log_2(\frac{CW_{max}}{CW_{min}})$ is the maximum of backoff stage. The scheduler of transmission overall the network depends on P_i. We assume that each node is notified about the success or failure of its transmitted packets. A packet is failure only when there is an interference on the intended receiver, in other terms, when a collision occurs on the receiver. We have considered previously infinite buffer size, therefore, there is no packet loss due to overflow at the queues. The only source of packet loss is due to collisions. For a reliable communication, we allow a limit number of successive transmissions of a single loosed packet, after that it will be dropped definitively.

2.4 Cross-layer representation of the model

The model of figure 1 represents our model in this paper. The two layers are clearly separated. Attempting the channel begins by choosing the queue from which a packet must be selected. And then, this packet is moved from the corresponding queue from the network layer to the MAC layer where it will be transmitted and retransmitted, if needed, until its success or drop. In this manner, when a packet is in the MAC layer, it is itself attempted successively until it is removed from the node.

2.5 Main notations

We summarize principle notations of the paper in the following two lists:

1. MAC layer notations:
   - P_i is the probability of transmission on the channel of the node i.
   - $P_{i,s,d}$ is the probability that a transmission from node i on the path from s to d is successful.
   - $K_{i,s,d}$ is the maximum number of successive collisions (or transmissions) allowed to a single packet sent from the node i on the path from s to d. After a $K_{i,s,d}$ failure, the packet is dropped. Note that the retry limit or the maximum number of retransmissions is $(K_{i,s,d} - 1)$.
   - $L_{i,s,d}$ is the expected number of attempts till successful or a drop from node i on the path from s to d.
2. Network layer notations:
   - f_i is the probability to send a packet from the queue F_i when it carries a packet.
   - $R_{s,d}$ is the set of intermediate nodes in a path between a node s and a node d. s and d are not in this set.
   - $R_{i,s,d}$ is the set of nodes $R_{s,i} \bigcup i$ in the path s, d.
   - $j_{i,s,d}$ designates a neighbor node of i that comes after i in the set $R_{s,d}$ toward the destination on the path from s to d. It is the next hop node of the node i.
   - π_i is the probability that the queue F_i has at least one packet to be forwarded after a departure of a packet. $y_i \triangleq 1 - \pi_i f_i$ appears to have a major information on load and stability of F_i in our previous works [2] and [3].
   - $\pi_{i,s,d}$ is the probability that the queue F_i has a packet at the first position ready to be forwarded to the path $R_{s,d}$ after a departure of a packet.
   - $P_{i,d}$ is the probability that the node i chooses the path $R_{i,d}$ (whose destination is d) for sending packets from Q_i. Normally, this parameter can be assigned to the node i transport layer decision.

3. A NEW DYNAMIC SCHEME FOR THE MAXIMUM NUMBER OF TRANSMISSIONS IN ROUTING

The maximum number of transmissions $K_{i,s,d}$ of each node i on a path $R_{s,d}$ appears to be an important parameter (in [2] and [3]) that can be adjusted easily by each node. When all nodes has the same static value K, it is sufficient to increase K so that throughput is considerably ameliorated but the load is not. A tradeoff stability-throughput is clearly felt. Is it possible to benefice from a dynamic value of $K_{i,s,d}$ to optimize this tradeoff?

In this section, we propose a new dynamic $K_{i,s,d}$ scheme based on a table-driven routing where routes are already known. It is a cross-layer scheme where each node needs the information about the route to determine the corresponding $K_{i,s,d}$ which is a MAC layer parameter. Each node in a path $R_{s,d}$ must know: (1) the length of the path in number of hop and (2) its position in the path in terms of number of hop that separates it from the source. When these two information are available, our scheme computes the corresponding $K_{i,s,d}$. The following is a description of the scheme:

Consider that each node has a default value of the maximum number of transmissions set to K. Each node i in the set $R_{s,d} \cup \{s\}$ computes the corresponding $K_{i,s,d}$ in such a manner that this latter is higher or equal to the previous $K_{j,s,d}$ where j is the previous node of i in the path $R_{s,d} \cup \{s\}$ i.e. $i = j_{j,s,d}$. Furthermore, the average values of $K_{i,s,d}$ (for $i \in R_{s,d} \cup \{s\}$) must be set to K i.e. $\frac{1}{|R_{s,d} \cup \{s\}|} \sum_{i \in R_{s,d} \cup \{s\}} K_{i,s,d} = K$. Also, the values of $K_{i,s,d}$ (for $i \in R_{s,d} \cup \{s\}$) are determined based on the position of the node i in the path $R_{s,d}$ i.e. it is based on the number of hop that separates it from the source or the destination. We add to this scheme a *reset technique* when the average queue size or the load of F_i exceeds some value. In fact, when the average queue value in dynamic case becomes not profitable in comparison to the static case, we reset the value of $K_{i,s,d}$ to K, or to a lower value. In the following section, we will specify a detailed and practical method for choosing $K_{i,s,d}$.

With this dynamic scheme, we aim to give more chance of success to packets that had come near to their destination. It does not mean that the end-to-end probability of success will be higher. It rather means that we need to avoid as much as possible loosing packets near their destination so that waste of bandwidth throughout a path becomes lower. In other terms, we expect to reduce the number of wasted slots in each connection.

Normally, the way of choosing good $K_{i,s,d}$ should depend on many parameters, not only on the number of hops of each connection but also on the transmission probabilities and the number of neighbors. Taking aware of many parameters at the same time is a complex issue. In this paper, we focus mainly on varying $K_{i,s,d}$ function of the number of hops. The following evaluation of performance section may clarify the interest of using dynamic $K_{i,s,d}$.

4. PERFORMANCE EVALUATION: NUMERICAL RESULTS AND SIMULATIONS

In this section, we evaluate the performance of the dynamic scheme for a symmetric linear and an asymmetric network. We specify and detail our dynamic scheme for choosing $K_{i,s,d}$ in terms of the hop number. Then an analysis of the numerical and simulation results are given. All numerical results have been validated with our discrete time simulator that is presented in paper [3].

4.1 Symmetric linear network case

4.1.1 Description of the network

Our purpose by studying the linear network case is to understand the advantage of the new dynamic scheme so that we can understand the efficiency of the method on the asymmetric case. Also, the linear symmetric network is simple to study. It eliminates the impact of neighboring and transmission probabilities. The characteristics of this network are as follow: we have (1) equal number of neighbors i.e. $n_i = 2$ for all nodes, (2) $P_i = P$ (3) infinite number of nodes, (4) equal forwarding probability i.e. $f_i = f$,(5) $P_{s,d}$, depends on the connection hop number of h, thus $P_{s,d} = P(h)$ (6) there is only one path between two different nodes i.e. one way to reach any destination from any source . The consequence of these hypothesis is that the stability is the same for all nodes i.e. $y_i = y$. When we take a uniform probability to choose a given path of length h, then $P(h) = \frac{1}{2B}$ where B represents the maximum number of hop to reach the most far destination.

4.1.2 Main Expressions for performance evaluation

We will mainly study the stability-throughput issue with the new scheme. In addition, the probability of success and the average number of transmissions bring additional material to understand what is happening in the network. Later, in the asymmetric network section, the end to end delay gives more information about stability of connections while in the symmetric linear network the stability of a node is equivalent for all nodes thus, the variation of a node stability informs about delay variation.

General expressions for performance evaluation were already derived in our paper [3]. Here, we rewrite these expressions in the symmetric linear case. Therefore, the stability region can be written as:

$$y = \frac{1}{1 + 2\sum_{j=1}^{B} \sum_{h=j+1}^{B} P(h) \prod_{k=1}^{j} (1 - T^{K(k,h)})} \tag{1}$$

where $T = 1 - P_{i,s,d}$, $P_{i,s,d} = (1-P)^2$ and $K(i,h)$ represents the value of $K_{i,s,d}$ (in $K(i,h)$ notation, i represents the position of the node on the path $R_{s,d}$, for example $K_{s,s,d} = K(1,h)$, $K_{j_{s,s,d},s,d} = K(2,h)$ and so on) of the node i on the path of length h. Let $L(i,h)$ be the $L_{i,s,d}$ of the node i on the path of length h. Thus, $L(i,h) = \frac{1-T^{K(i,h)}}{1-T}$. Since the network is symmetric, the $\overline{L_i}$ for all i are the same, then $\overline{L_i} = L$ where L can be written

$$\begin{aligned} L &= 2\frac{(1-y)}{B^2 - B} \sum_{j=1}^{B} \sum_{h=j+1}^{B} L(j,h) \\ &\quad + y \sum_{h=1}^{B} P(h) L(1,h) \end{aligned} \tag{2}$$

where $\pi_{i,s,d} = \frac{\pi_i}{B^2 - B}$ and $(B^2 - B)$ is the number of connections that traverse a node. Note that L depends only on y and B for a given P. Therefore, L for the dynamic case is different from the static one. The throughput on the path of length h can be written as:

$$thp(h) = yP(h)\frac{P}{L} \prod_{k=1}^{h} (1 - T^{K(k,h)}) \tag{3}$$

The average throughput for all h is

$$\overline{thp} = y\frac{P}{B.L}. \sum_{h=1}^{B} P(h) \prod_{k=1}^{h} (1 - T^{K(k,h)}) \tag{4}$$

The probability of success between a couple of nodes on a path of length h is $Psucc(h) = \prod_{k=1}^{h}(1-T^{K(k,h)})$. The average probability of success for all h is $\overline{Psucc} = \frac{1}{B}\sum_{h=1}^{B} Psucc(h)$.

4.1.3 A practical description of a dynamic method

We use a simple method that gives a dynamic value of $K(i,h)$ depending on h the length of a connection, on the position of the node i on the path $R_{s,d}$ and K' the step of how much we increase K on a given node i. Each node i initializes $K(i,h)$ to K.

This method maintains an average K of all $K(i,h)$ (for $i \in R_{s,d} \cup \{s\}$) values of each connection. For example, this average K can be the default value of the maximum number of transmissions in a network of static K. Also, in this manner it will be easy to compare the static K case performance and the dynamic one.

Practically, for each packet transmission, a node i must knows its $K(i,h)$ on a given path (or connection) of length h. In fact, it must determines from the routing layer the length h of the path, then its position related to the source. Supposing that K and K' are known, node i can calculate easily its corresponding $K(i,h)$ while maintaining an average K in the path. Then, it informs the MAC layer about this $K(i,h)$ new value.

As an exterior observer point of view, the $K(i,h)$ values are attributed as follow: the middle node has the value K (when h is even, we attribute K to the 2 middle nodes) and on its both side, K is decreased (in the direction of the source) and increased (in the direction of the destination) by a value of K' for each hop. On one side, whenever it is impossible to decrease K, the value of $K(i,h)$ maintains its last value. On the other side, $K(i,h)$ must maintains also the last value in a certain level so that we maintain an average of K.

For example, when $h = 10$, $K = 8$ and $K' = 2$ the set values of $K(i,h)$ attributed to the set of nodes in $R_{s,d} \cup \{s\}$ starting from the source and ending with the node before the destination, is: $\{2, 2, 4, 6, 8, 8, 10, 12, 14, 14\}$. In this case, we have for example $K(4,10) = 6$, $K(5,10) = 8$, etc. We could also use another method to attribute values of $K(i,h)$. The key idea of the dynamic scheme function of the number of hop, in this section, is that we attribute the values of $K(i,h)$ in an increasing manner starting from the source of a connection till the destination. For that a simple algorithm can be turned on each node to determine its corresponding dynamic K to a given route $R_{s,d}$.

4.1.4 *Analysis of the numerical results*

We draw some numerical results of the above formulas using the previous parameters: $B = 10$ and $K = 8$ for the two cases - $K' = 0$ and $K' = 2$. The maximum hop number $B = 10$ allows about $2 * 10$ possible connections for each node. The forwarding probability is set to $f = 0.8$. The numerical results concern the average number of transmissions and stability for each node, then the end to end throughput and probability of success (for some connections and the average of all connections). We are interested to evaluate the behavior of these, for each transmission probability i.e. when the channel suffer from low to high contention. All these are shown from figures 2 to 5. The main remarkable thing is that the stability and the throughput are considerably ameliorated with the dynamic scheme ($K' \neq 0$) compared to the static K case ($K' = 0$).

This remarkable amelioration is mainly due to the fact that:

- the dynamic scheme privileges the forwarded packets that come near the destination. It is better to encourage these packets to reach their destination, if not, the network will suffer more wasted bandwidth.

- the flow of packets from each source are been limited on the first hops of each connection. If the network cannot support transporting more packets on a connection, it is better to limit the flow of new entering packets in the network. This is a load moderating issue.

As a consequence, figure 2 shows that the average number of attempts in the dynamic scheme $(L(K' \neq 0))$[1] is always lower then the one of the static K $(L(K' = 0))$: $L(K' \neq 0) \leq L(K' = 0)$. It means that a packet needs in average less retransmissions at each node throughout a path $R_{s,d}$ to be delivered on the destination, in the dynamic case. Therefore, the service rate of the forwarding packets will be faster. As shown in figure 3, it has permitted a low load and more new packets have entered the network, indicating a higher region of stability. For that, $y(K' \neq 0) \geq y(K' = 0)$.

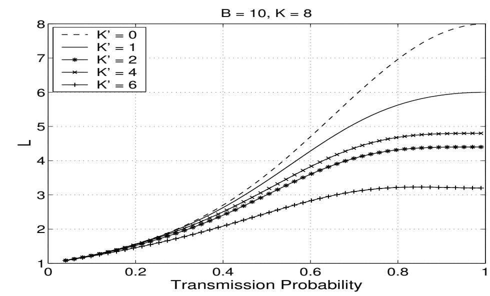

Figure 2: Average number of transmission L for different K'

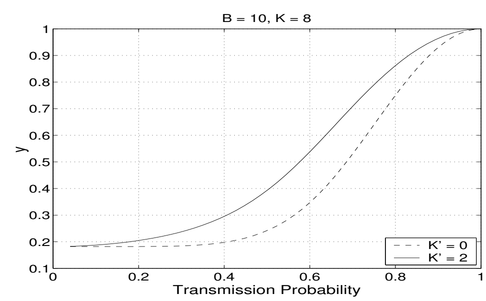

Figure 3: Stability region for the linear case with static and dynamic K

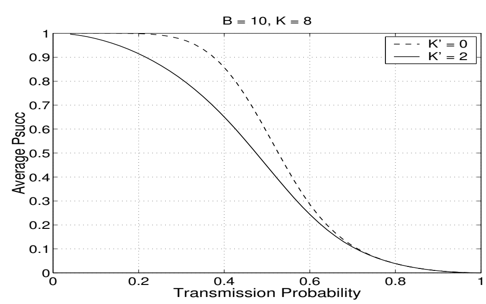

Figure 4: Average Probability of success for the linear case with static and dynamic K

We distinguish two states of the network for two contention degrees when we use the dynamic scheme. These are shown on figure 4 where for a given P_0 ($P_0 \simeq 0.55$ in this example), the probability of success for $K' \neq 0$ comes near the one for $K' = 0$. Therefore, we distinguish:

- The *severe state* for a *low-moderate* contention: $P \leq P_0$ and $\overline{Psucc}(K' \neq 0) < \overline{Psucc}(K' = 0)$. In this

[1] Let $X(K' \neq 0)$ and $X(K' = 0)$ be 2 symbols where X represents one of the parameters in the set $\{K, L, y, \overline{thp}, \overline{Psucc}\}$ for the two dynamic and static K case respectively.

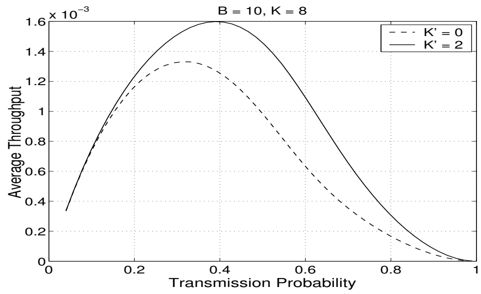

Figure 5: Average throughput for the linear case with static and dynamic K

state, the nodes with $K(K' \neq 0) < K$ have the aptitude to drop a lot of packets in the first nodes (near the source) on a path $R_{s,d}$, in such a manner that a less number of successful packets arrives to the destination compared to the static K case. When dropping a lot of packets in the network, the load of each node diminishes, thus $y(K' \neq 0) \geq y(K' = 0)$. Since the impact of the load in this state is higher than the end to end probability of success, the average throughput in the network becomes larger i.e. $\overline{thp}(K' \neq 0) \geq \overline{thp}(K' \neq 0)$, see figure 5. In low contention, we does not really need to limit a lot the retransmission of packets since they have a higher chance to reach the destination in the static K case. The load control appears to be more efficient than controlling the success of packets to get a good throughput.

- The *moderate state* for a *moderate-high* contention: $P \geq P_0$ and $\overline{Psucc}(K' \neq 0) \simeq \overline{Psucc}(K' = 0)$. In this state, dropping packets with $K(K' \neq 0) < K$ is more efficient than the *severe state*, in such a manner that even the end to end probability of success comes closer to the static case. In high contention, a packet that has traveled through many nodes in the static K case is more susceptible to drop. When dropping such packet, we loose all retransmission slots from the source until its drop. Therefore, increasing K behind the middle node on a path $R_{s,d}$ helps conserving the packets from drop and minimizes the number of loosed slots. In this way, the throughput and the load are ameliorated as shown in figures 5 and 3 respectively. This also can be verified with figure 2 where $L(K' \neq 0) \leq L(K' = 0)$.

These two states can merge to a one state for some values of K, K' or B, yet the dynamic scheme maintains its advantage compared to the static K case.

4.1.5 Impact of B, K and K'

We study the impact of B, K and K' on the performance of the network. We proceed by comparing the static and the dynamic case. We show on figures the gain ratio while using the dynamic case in terms of these last parameters. The gain ratio of the static-dynamic K for the average throughput and the stability region, presented in figures from 7 to 10, is defined as: $\frac{X(K' \neq 0) - X(K'=0)}{X(K'=0)}$ where X is the average of $\overline{thp}$ or y for all P. From these figures, the gain ratio of the average throughput and the stability region evolve in a similar way when varying B, K or K'. Remark that the average throughput is mainly affected by the load variation of each node from the equation 4.

- Impact of B: Let ΔL be the difference between the average number of transmissions for $K' = 0$ and $K' \neq 0$ i.e. $\Delta L = L(K' = 0) - L(K' \neq 0)$. ΔL is an increasing function with B as shown in figure 6 which verifies the increasing gain ratio of the figure 7. The dynamic scheme has a good performance in large multi-hop networks .

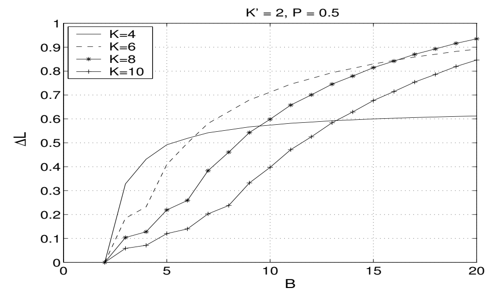

Figure 6: ΔL versus B for different K, for $K' = 2$ and $P = 0.5$

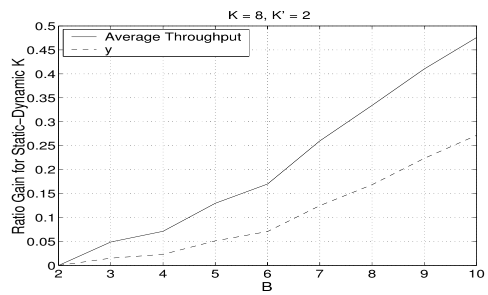

Figure 7: Gain ratio of dynamic case compared to the static one versus B (linear network)

- Impact of K: When K tends toward large values, the two dynamic and static cases tend to each other i.e. we tend to zero gain ratio. So each packet will be retransmitted until a success. It does neutralize any dynamic scheme. Also, the impact of K depends on K' as we see in figures 8 and 9. For some K near the value of K' or multiple of it, we have picks of gain ratio that decrease with K. For $K = 4$, we have the maximum possible gain in these two figures. It is a question of how we use K' according to K so that the dynamic scheme operate in an optimal point. For a fixed K' and P, ΔL function of K for small B in figure 6 decreases with K, so in figure 8 the gain ratio is also decreasing. Remark that figure 8 (as figures 7, 9 and 10) presents the gain ratio for all P, whereas figure 6 is presented for a fixed $P = 0.5$. Therefore, for $P = 0.5$ and large B, the higher is K, the better becomes the dynamic scheme. For that, the impact of B is considerable compared to K.

- Impact of K': The dynamic scheme is defined for $K' \leq K$. From figure 10, choosing $K' = 6$ for $K = 8$ causes severe drops at the beginning of a path since $K(K' \neq 0) = 2$ for $K(K' \neq 0) < K$. Even though the gain ratio is clearly large. The difference between the point $K' = 2$ and $K' = 4$ in figure 10 is explained by the figure 2 where $L(K' = 2) < L(K' = 4)$.

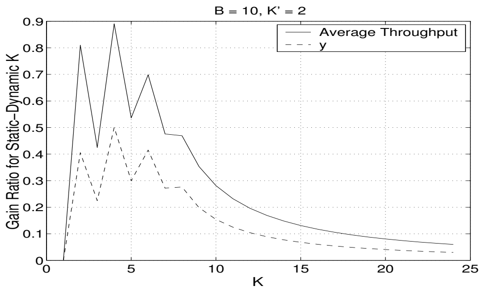

Figure 8: Gain ratio of dynamic case compared to the static one versus K for $K' = 2$ (linear network)

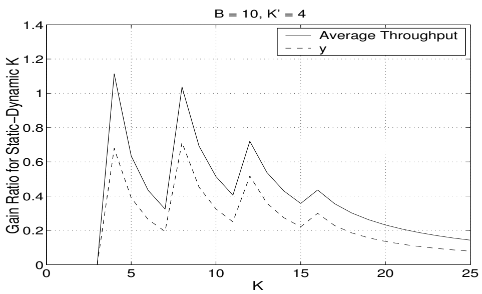

Figure 9: Gain ratio of dynamic case compared to the static one versus K for $K' = 4$ (linear network)

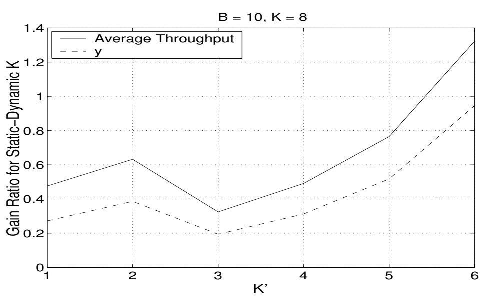

Figure 10: Gain ratio of dynamic case compared to the static one versus K' (linear network)

Moreover, whatever is the series of $K (K' \neq 0)$ on a given path, the average number of transmissions from figure 2 can identify the performance of the dynamic scheme for any B, K and K'.

4.2 Asymmetric network case

Consider an asymmetric static wireless network with 11 nodes as shown in figure 11. We choose the parameters $f_i \equiv f$ and P_i in a manner of enabling stability, for all i. We fix $f = 0.8$. Let $P_2 = 0.3, P_3 = 0.3, P_4 = 0.4, P_5 = 0.5, P_7 = 0.3, P_8 = 0.3, P_{10} = 0.4$ be the fixed transmission probabilities for nodes 2, 3, 4, 5, 7, 8 and 10 while $P_i \equiv P$ for all other i. Many nodes need to have a fix transmission probabilities so to get a stable queues for all nodes. The default maximum number of transmission is K. In the static case, $K_{i,s,d} \equiv K$, while in dynamic case $K_{i,s,d}$ is chosen using the dynamic scheme presented previously (paragraph 3 and 4.1). We implement this dynamic scheme in our discrete time simulator, so we can evaluate performance and validate the numerical results with simulations.

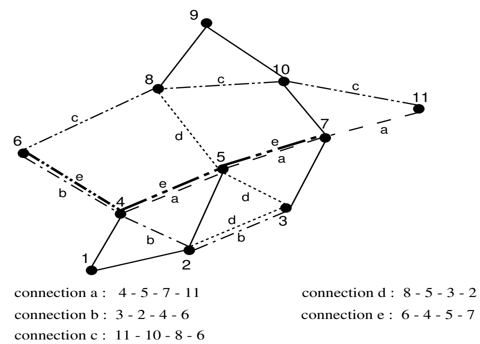

Figure 11: Wireless network

4.2.1 A first numerical and simulation study

Let a, b, c, d and e be the five connections established on the network of figure 11, as indicated in the same figure.

We can compare from Figures 12 to 16 the dynamic ($K = 4$ and $K' = 1$) and the static ($K = 4$ and $K' = 0$) cases. Note that $y_j = 1$ for $j \in \{1, 6, 9, 11\}$, these nodes do not forward packets as shown in figure 11.

Firstly, the forwarding source nodes (3, 4 and 8) of the connections a, b and d have been affected small dynamic K for their new packets (packets from Q): $K_{3,3,6} = K_{4,4,11} = K_{8,8,2} = 3$ and higher dynamic K for their forwarding packets: $K_{3,8,2} = K_{4,3,2} = K_{8,11,6} = 5$ and $K_{4,6,7} = 4$. In fact, there are two advantages on giving smaller K for new packets. The first one, it gives more priority to the forwarding queue. Therefore, we observe less load, then more aptitude to send new packets. The second one, it can optimize the load on the nodes belonging to the source connection, in a saturated network case. In fact, it can occur severe drops of new packets (due to small K) that can diminish the flow of packets in a connection and maintain necessary packets. Figure 12 supports our comment: the stability region or the aptitude of sending new packets is considerably ameliorated in nodes 3, 4 and 8. In addition, the throughput of connection d has beneficed from the increase of y_8 of its source node 8, while the two others a and b has maintained their throughput approximatively unchanged.

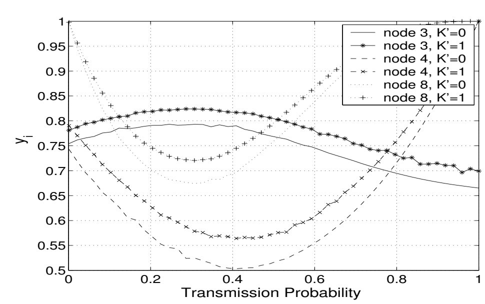

Figure 12: Stability region y_i of the dynamic (K'=1) and static (K'=0) cases for K=4 (nodes 3, 4 and 8 of the asymmetric network of figure 11)

Secondly, as the node 6 and 11 don't forward packets in our example, then $y_6 = y_{11} = 1$. These two nodes are the source of connections e and c respectively. From figure 14,

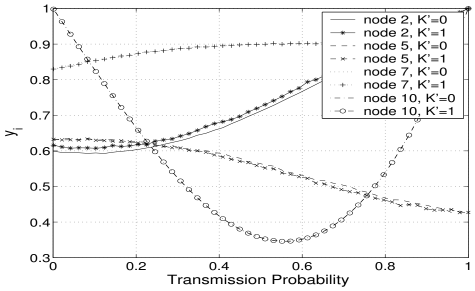

Figure 13: Stability region y_i of the dynamic (K'=1) and static (K'=0) cases for K=4 (nodes 2, 5, 7 and 10 of the asymmetric network of figure 11)

the throughput of these two connections are clearly higher in the dynamic scheme and does not depend on any forwarding queue loads in these connections. However, the packets sent from node 6 and 11 are limited by the fact that $K_{6,6,7} = K_{11,11,6} = 3$, but there are privileged at nodes 5 and 8 with $K_{5,6,7} = K_{8,11,6} = 5$. Each drop at these latter nodes is more expensive than the drop at the source nodes (as explained previously). For that, the throughput of these connections (of figure 14) was only affected by the end to end success of packets in an interval of time without the impact of y_6 and y_{11} which are the sources aptitude of sending new packets. Note that nodes 2, 5, 7 and 10 have not really changed their region stability with the dynamic scheme in this example (see figure 13).

Thirdly, the end-to-end delay of a connection gives a global vision on the stability of nodes that forms this connection. Precisely, it is mainly affected by the waiting time on the forwarding intermediate queues. In figure 15, the high delay of connection c clearly reflects the high and moderate charge of nodes 10 and 8 shown in figures 13 and 12 respectively. In figure 16, connection a has maintained the same delay in the dynamic as in the static case. This was a consequence of the y_5 and y_7 unchanging (not so changed) in these two cases. Delay of connections b, c and e have been ameliorated in the dynamic case due to the forwarding aptitude of source nodes 4 and 8 that belong to these connections.

What about the gain percentages of our scheme compared to the static one? We can observe from the presented figures that the gain varies in function of the probability of transmission. Therefore, for a $P = 0.4$, the throughput amelioration reaches 20% for connection d and is around 9% for connections c and e. The delay for this same P is around 15% for connection b and around 11% for connections c and e.

4.2.2 Discussion

In sum, the dynamic scheme has its better performance when some of the source nodes collaborates by forwarding packets and when these kind of sources are well distributed in the network. In fact, there are two properties that help a connection to get a good performance: (1) a connection must include within its intermediate nodes a source node of an other connection (2) the source node of a connection must not forward packets. The first one ameliorates the delay and the second one the throughput. These two properties are found on connections c and e. Furthermore, the good performance (of throughput and delay) of connection c and e confirm this conclusion. These are generally the case

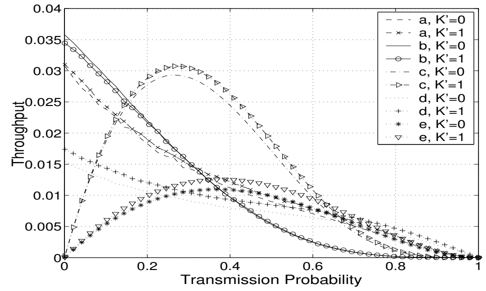

Figure 14: Throughput of the dynamic (K'=1) and static (K'=0) cases for K=4 (nodes 2, 5, 7 and 10 of the asymmetric network of figure 11)

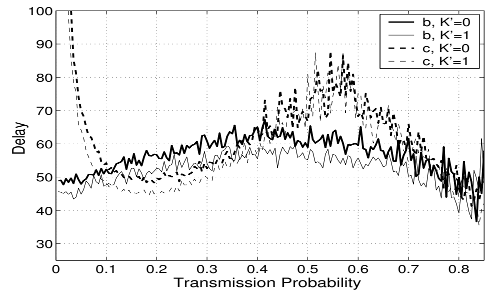

Figure 15: Delay of the dynamic (K'=1) and static (K'=0) cases for K=4 (Connections b and c of the asymmetric network of figure 11)

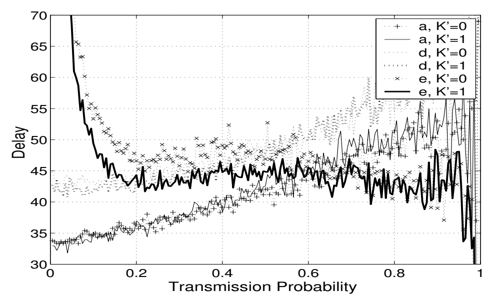

Figure 16: Delay of the dynamic (K'=1) and static (K'=0) cases for K=4 (Connections a, d and e of the asymmetric network of figure 11)

of connections established from the boundary source nodes of an ad hoc network. When one of these two properties is not found, then three *situations* are presented: a connection of the dynamic scheme (1) maintains unchanged one performance criteria (throughput or delay) and ameliorate the other one, (2) deteriorates one performance criteria and ameliorate the other one, (3) maintains unchanged the performance. These three situations are with comparison to the static case. In the second one, the new scheme does not overcome the existing tradeoff throughput-delay for a given connection, but it enables a benefice to other connections. To overcome this tradeoff of some given connections of this second situation, we have introduced on the new dynamic scheme the capability to reset the dynamic value of K i.e. to re-allocate the default value K instead of the dynamic value only on the case where $K(K' \neq 0) > K(K' = 0)$. We study this option of re-allocating K in the next section and we call it the *reset technique*.

4.2.3 *A second simulation study with the* reset technique

Here, we consider only three connections a, b and f where f is formed by the successive nodes $9-10-7-3$ with node 9 as a source and node 3 as a destination. a and b are the same as previously. Connection b causes node 4 to forward. The default value of K is maintained to 4. But, we choose $K'=3$. In this manner, the value of $K(K'=3)$ for node 7 is set to 7 for the two connections a and f. Therefore, the stability of node 7 becomes critical and is penalized when the contention on the channel increases: many retransmissions of each single packet causes more additional waiting time on the forwarding queue. So the choice of high $K(K'=3)$ on this node is not really judicious for itself as shown in figure 17: $y_7(K'=3) < y_7(K'=0)$, and nor for the connection delays as shown in figure 19. However, a considerable amelioration on the throughput is clearly observed in figure 18.

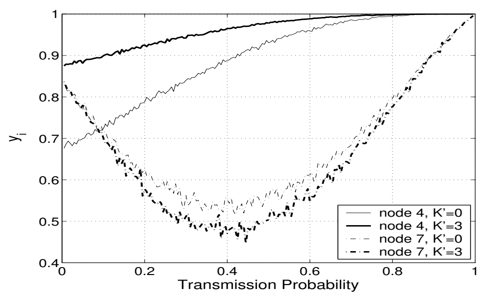

Figure 17: Stability region y_i of the dynamic (K'=3) and static (K'=0) cases for K=4 (asymmetric network of figure 11)

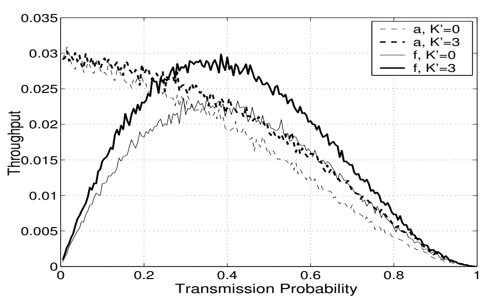

Figure 18: Throughput of the dynamic (K'=3) and static (K'=0) cases for K=4 (asymmetric network of figure 11)

These observations correspond to the second situation described previously. Each node suffering from a degradation of stability appeals the *reset technique*. In fact, each node uses the following three steps to test and apply if needed, the *reset technique*:

1. computes $y(K'=0)$ (assume that necessary information to compute it are known) and compares it to $y(K'\neq 0)$ (measured value). If $\frac{y(K'\neq 0)-y(K'=0)}{y(K'=0)}$ is negative and the absolute value higher than a given threshold [2],then go to the second step, else do nothing,

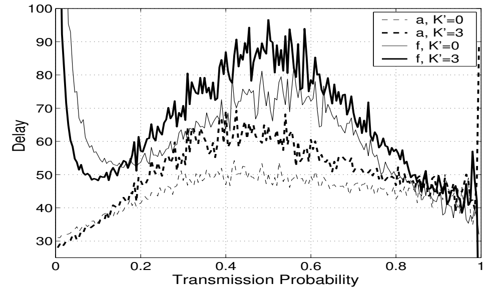

Figure 19: Delay of the dynamic (K'=3) and static (K'=0) cases for K=4 (asymmetric network of figure 11)

2. chooses judiciously a connection (according to its data type and if it is not yet chosen) between those traversing it,

3. applies the reset of $K(K'\neq 0)$ to the default value K i.e. set $K(K'\neq 0)\equiv K$ for the connection chosen in step 2.

On our example, the reset technique is applied to the node 7 of the connection f. Figures 20, 21 and 22 show that node 7 and connection f restore their performances as in the static case. The remarkable thing is that even the connection a has seen its delay ameliorated due to the load reduction on the node 7 forwarding queue. While on other hand the throughput of a was not really affected in this example. Hence, after applying the *reset technique* to node 7, connections a and f are now classified in the first and the third situation respectively.

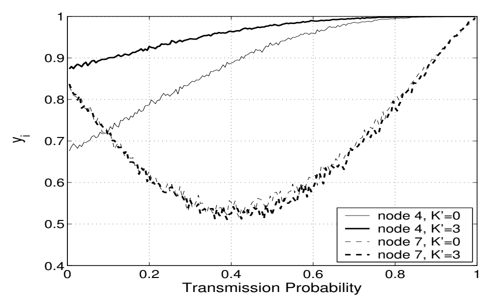

Figure 20: Stability region y_i of the dynamic (K'=3) and static (K'=0) cases for K=4 with a reset of the K value of node 7 (asymmetric network of figure 11)

5. CONCLUSION

In this paper, we have presented a new cross-layer scheme using the maximum number of transmissions parameter in a saturated ad hoc network, so a dynamic routing can be achieved . The performance evaluation study using analytical and simulation tools has shown that in the case of symmetric linear networks the scheme significantly improves the

[2]we can take the average number of packets in queue as a criteria to decide whether we use or not the reset technique.

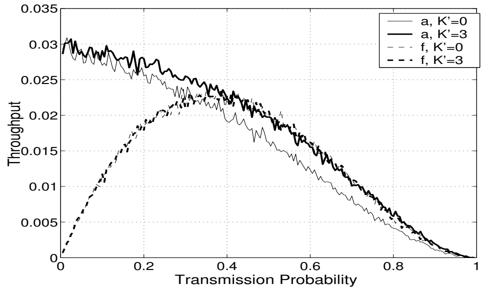

Figure 21: Throughput of the dynamic (K'=3) and static (K'=0) cases for K=4 with a reset of $K(K'=3)$ on node 7 of connection f (asymmetric network of figure 11)

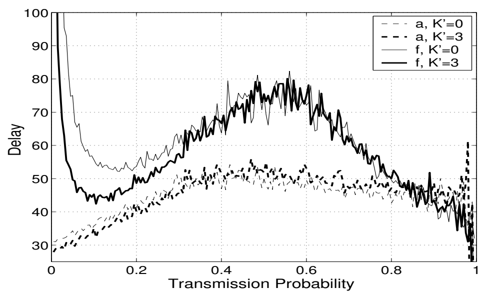

Figure 22: Delay of the dynamic (K'=3) and static (K'=0) cases for K=4 with a reset of $K(K'=3)$ on node 7 of connection f (asymmetric network of figure 11)

stability and the throughput for all transmission probability. We have also studied the impact of several parameters such as the maximum length of connections and see that we take benefice from large connections. On other hand, asymmetric networks performances are directly related to the topology and the neighboring distribution. However, we have identified two properties that a connection must have to get both the throughput and the delay ameliorated. If one of these is not presented then connection performance can be classified on one of 3 situations where we can benefice or leave unchanged the performances. A *reset technique* was integrated to the scheme so to optimize performances. This work can be helpful for routing design in ad hoc networks.

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