Light Weight Distributed QoS Adapter in Large-Scale Ad hoc Networks

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Abstract: Considering the comfortably establishing ad hoc networks, the use of this type of network is increasing day to day. On the other side, it is predicted that using multimedia applications will be more public in these network. As it is known, in contrary to best-effort flows, the transmission of multimedia flows in any network need support from QoS. However, the wireless ad hoc networks are severely affected by bandwidth, and establishing a QoS in these networks face problems. In this paper, we have proposed a thoroughly distributed algorithm to support the QoS in ad hoc networks. This algorithm guarantees the QoS of the real-time applications vis-a-vis each other and best-effort flows as well. The algorithm suggested in this paper dynamically regulates the Contention Window of the flows and serves the flows in terms of their requests QoS choosing the smallest CW in every node. This algorithm also uses the fixed and/or less stationary nodes for the transmission of real-time flows by increasing the QoS of the multimedia flows. This algorithm is preferred because it prioritizes the flows that are of the same class but have not obtained favorite QoS compared to other flows of the same class in addition to classifying the flows in the network and offering better services to the classes of higher priority. All this occur without the controlled packets forwarding and resource reserving and freeing method. We have proved the correctness of this algorithm using Markov's mathematical model.

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1. Introduction

A wireless ad hoc network consists of a number of nodes communicating with each other on wireless links without infrastructure support. A multi hop ad hoc network is an ad hoc network in which the packets of a traffic flow are relayed by one or more intermediate nodes before they reach the destination. To support different types of real time applications, providing various quality of service (QoS) guarantees for multi-hop flows is an important issue in wireless ad hoc networks.

Many routing schemes and frameworks have been proposed to provide QoS support for ad hoc networks [1, 2, 3, 4, 5]. Among them, INSIGNIA [1] uses an in-band signaling protocol for distribution of QoS information. The term in-band signaling means that the control information is carried with data, and there is no separate control channel as opposed to another type of signaling called out-of-band signaling. INSIGNIA's architecture has several modules that are routing, in-band signaling, admission control, packet forwarding or scheduling, MAC protocol, etc. However, it is a stateful architecture because it uses soft state resource management scheme to utilize the resources.

SWAN [2] improves INSIGNIA by introducing an Additive Increase Multiplicative Decrease (AIMD)-based rate control algorithm. It supports service differentiation for real-time and best-effort traffic. The SWAN's architecture handles both the real-time traffic and the best-effort traffic. Local rate control is used for handling the best-effort traffic of TCP, and a sender-based admission control is used for the real-time traffic of UDP.

Both [3] and [4] utilize a distance vector protocol to collect end-to-end QoS information via either flooding or hop-by-hop propagation. CEDAR[5] proposes a core-extraction distributed routing algorithm that maintains a self-organizing routing infrastructure, called the “core”.

Most of the available algorithms do not have any control over the reception of the new flows. And some algorithms control the reception of the flows by exerting overhead on the network and exchanging control messages between the nodes in the path. These protocols do not attend to the fact that the transmission of the flows in a node may decrease the bandwidth of the available nodes in the scope of the node transmission. Therefore, these protocols only guarantee that the new flows will reach the desired QoS, but do not deed the point that the reception of the new flow may cause decrease in the QoS of the current flows. A solution to this problem is that the effort rate of the nodes in the path of the new flow transmission to obtain an environment be taken into account in deciding about the reception of the new flow. However, it is possible for some nodes in the path not to be directly accessible for the decision-making nodes and to need multi-hop facilities. As it is seen, this method can exert too much overhead on the network. On the other hand, this method will not have desirable results for high rate of packets loss and movement of the nodes in the ad hoc networks. As such, the algorithms supporting the QoS must not be sensitive to the packet loss and must not exert much overhead on the network, which have been taken into account in our method.

Recently, other works have been proposed to improve the performance of MAC protocols and the support of service differentiation. Many of these approaches specifically target IEEE 802.11 [6]. For example, studies in [7,8,9,10] propose to tune the contention windows sizes or the inter-frame spacing values to improve network throughput, while studies in [7,11,12,13,14] propose priority-based scheduling to provide service differentiation. Most of this work utilizes different back-off mechanisms, different DIFS lengths, or different maximum frame lengths, based on the priority of the traffic.

However, the current status of the network and the QoS acquired by the flows are not given attention when these values are considered. In other words, these algorithms do not act fully automatically when priorities are given to the flows.

In this paper, a fully distributed algorithm is proposed for supporting the QoS of the flows in the network. Classifying the flows to delay-sensitive, bandwidth-sensitive and best effort, this algorithm differentiates the flows in the network in order to offer services.

This algorithm is preferred to others because, without any control packet, it gives much priority to the flows which are of the same class but have not obtained favorable QoS compared to other peer flows and tries to remove lagged QoS in these flows in addition to classifying the flows in the network. To put it another way, in addition to the type of the flows it attaches attention to the QoS different flows have acquired.

The rest of the paper is organized as follow. Section 2 is concerned with the QoS framework, algorithms and works done to classify the flows and support the flow QoS. In Section 3, the validity and properness of the suggested model is proved through Markov's Chain, and Section 4 is associated with conclusion.

2. QoS Framework

2.1. Desirable Network Modification

Our aim is to realize the QoS of the real time flows in the ad hoc networks vis-à-vis best-effort flows.

Many routing protocols in the ad hoc networks do not differentiate between fixed nodes, less mobile and mobile nodes for the transmission of the flows in multi-hop environment. In other words, there is an equal chance for the fixed, less mobile and mobile nodes to be chosen in the flow transmission though the fixed nodes and/or less mobile nodes offer better quality in the flow transmission. Thus, it is suggested fixed routers and/or less mobile routers be taken into account in special places of vast environments so that the transmission can be done with better quality. While best-effort traffic may be more tolerant to node mobility, the quality of real-time traffic will be significantly degraded and is likely to become unacceptable. The utilization of fixed wireless routers in these networks will greatly improve the quality of real-time traffic by the elimination of intermediate link breaks.

2.2. Find_Fix_Routers for real-time traffics

When a node wants to send a real-time flow, it must, first of all, call for Find_Fix_Router process in order to find a valid path. By a valid path, it is meant a path which is composed of fixed nodes and/or lea mobile nodes and provides for the QoS of the desirable flow.

Find_Fix_Router process based on the modified AODV routing protocol. The modified protocol reflect the selection of stationary routes for real-time traffics. When a source node initiates route discovery for real-time traffic with strict quality requirements, only the fixed routers respond to the control packets by either forwarding the RREQ, or unicasting a RREP. The mobile nodes do not respond to these packets, unless they are the destination.

Find_Fix_Router also enables effective admission control when the network utilization is saturated. This requires accurate estimation of channel utilization and prediction of flow quality, i.e., throughput or transmission delay. The proposed QoS approach is based on model-based resource estimation mechanism, called *MBRP*[17]. By modeling the node back-off behavior of the MAC protocol and analyzing the channel utilization, MBRP provides both per-flow and aggregated system wide throughput and delay [16].

2.3. Prioritized medium access

In Ad hoc networks, priority scheduling algorithms are based on IEEE 802.11[6].Currently, there are several approaches that propose to provide service differentiation to different types of traffic based on 802.11, by either assigning different minimum contention window sizes ($CW_{\min}$), Arbitrary Inter Frame Spacings (AIFS), or back-off ratios.

There are algorithms that differentiate between different flows through these techniques, but this differentiation is static. That is to say, it does not heed the network current status and current status of flows. Therefore reduces the usage efficiency of the network. So, we propose an adaptive scheme to manage trade-off. The basic idea is that, because the state of ad hoc networks can vary greatly due to mobility and channel interference, it is advantageous to adjust the back-off behavior according to the current channel condition and current QoS of flows.

To achieve service differentiation, as well as to adapt to the current network usage, we combine the collision rate and current QoS of flows with the exponential back-off mechanism in IEEE802.11. To do it, classifies flows into three types: delay-sensitive flows, bandwidth sensitive flows and best effort flows.Upon receiving the first packet from the flow related to one of the three classes, each node in the network builds a queue for that flow locally and without any overhead. Then it inserts this packet and subsequent packets related to that flow in this queue. The purpose of queuing each special flow is to manage and control the QoS obtained by each flow in every node and in the whole system consequently. The proposed algorithm does not let a flow obtain a quality higher than the requested quality. On the other hand, it tries to provide the quality requested by each flow. It is noted that contrary to real-time flows where a separate queue is built in every node for each flow, only a queue is built for all best-effort flows in every node. Figure 1 shows the queues built in each node to manage different flows.

classes in order to differentiate the flows. As such, the level of offering services to the flows in the network is personalized with consideration of the type of the flow class and the QoS they have obtained. These three classes and the algorithms used to regulate the level of the service offered to the flows are discussed in this Section.

The delay-sensitive flows, such as conversational audio/video conferencing, require that packets arrive at the destination within a certain delay bound. The bandwidth-sensitive flows, such as on-demand multimedia retrieval, require a certain throughput. The best effort flows, such as file transfer, can adapt to changes in bandwidth and delay. Due to the different requirements of flows, each type of flows has its own contention window adaptation rule, as flows:

1) Delay-Sensitive Flows: For a delay-sensitive flow, the essential QoS requirement is end-to-end packet delay, which we call d.

To control delay, the *d* must be broken down into per-hop delay requirements. To maintain the aggregated end-to-end delay below *d*, each hop locally limits packet delay below its per-hop requirement. For this paper, each node is assigned with the same per-hop delay requirement, *d/ m*, where *m* is the hop count of the flow. It is noted that the value of m is calculated through AODV routing algorithm.

$$CW^{(n+1)} = CW^{(n)} * \left(1 + a \frac{d/m - D^{(n)}}{d/m}\right) \qquad (1)$$

Where the superscript n represents the n^{th} update iteration, *D* denotes the actual peak packet delay at the node during a update period and α is a small positive constant (α=0.1).

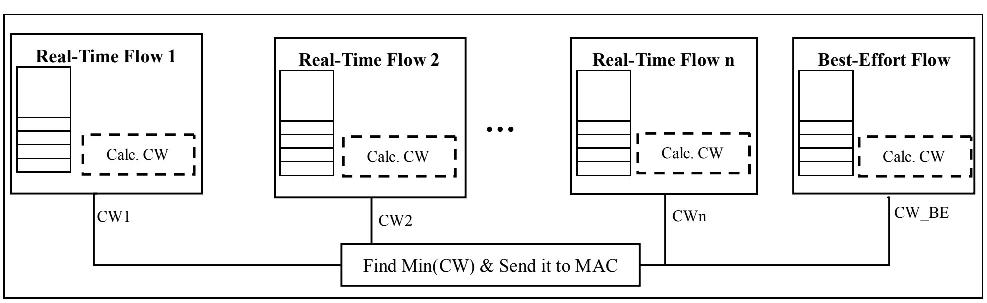

Figure 1. Queues in each node (Network Layer)

2.4 Algorithms Used to Control QoS of Flows

In the algorithm proposed in this paper, the flows in the network are divided to three different

2) Bandwidth-Sensitive Flows: For a bandwidth sensitive flow, the essential QoS requirement is throughput. For control throughput it is requires that at each node along the flow's route, the packet arrival rate of the flow should match the packet departure rate of the flow. In order for the rate of packet input to the node to be equal to the rate of packet output from the node, a queue must be used and its length must be managed. Therefore, it is suggested CW of the flows sensitive to bandwidth be calculated as follows:

$$CW^{(n+1)} = CW^{(n)} + \beta(q - Q^{(n)}) \quad (2)$$

Where q is a threshold value of the queue length that is smaller than the maximum capacity of the queue, Q represents the actual queue length and β is a positive constant ($\beta=1$). If Q is larger than q, the algorithm decreases *CW* to increase the packet departure rate to decrease queue length. If Q is smaller than q, the algorithm increases *CW* to decrease the packet departure rate and free up resources for other flows. As the queue size varies around the threshold value q, the average throughput of the flow matches its requirement.

3) Best Effort Flows: Best effort flows are tolerant to changes in service levels and do not have any hard requirements about bandwidth or packet delay. The purpose of updating the contention window size of best effort flows is to prevent best effort flows from congesting the network and degrading the service level of real-time flows and this is done by controlling the network congestion.

$$CW^{(n+1)} = CW^{(n)} \times (1 + \gamma(f - F^{(n)})) \quad (3)$$

Where f is a *congestion threshold* for idle channel time, F is the actual idle channel time and γ is a positive constant ($\gamma=0.1$).

When the average idle channel time F is smaller than the threshold value f, the network is considered congested and the contention window size of the best effort traffic is increased to avoid decreasing the service level of real-time traffic. On the other hand, if the network is lightly loaded so that the idle channel time is larger than f, the contention window size of best effort traffic is decreased so that the idle bandwidth can be utilized.

Later on, pseudo-codes related to the packet forwarding, packet receiving, CW calculation and back-off computation will be discussed.

When a node receives a packet do the following:

Receive_Packet(P)

```
{
  If (TypeOf(P)='Best-Effort') then
     If (there is no queue for Best-Effort flow) then
          Create a queue for Best-effort flow;
  Else if (p is the 1th packet of non B_E flow) then
          Create a queue for this flow;
     Add packet in specific queue;
}
```

When a node want to send a packet do as following:

Packet_Send()

```
{
   Indicated which flow the smallest CW relates to.
   If (TypeOf(flow)='Real-Time') then
        Find_Fix_Routers();
   Remove a packet from queue;
   Send packet;
   Update queue pointers;
}
```

Each of nodes performs following instructions to calculating CW for each flow.

Calc_CW ()

{

If (TypeOf(flow) = 'delay-sensitive' **then**

$$CW^{(n+1)} = CW^{(n)} * (1 + a\frac{d/m - D^{(n)}}{d/m})$$

elseIf TypeOf(flow) = 'bandwidth-sensitive' **then**

$$CW^{(n+1)} = CW^{(n)} + \beta(q - Q^{(n)})$$

elseIf TypeOf(flow) = 'best-effort' **then**

$$CW^{(n+1)} = CW^{(n)} \times (1 + \gamma(f - F^{(n)}))$$

}

The IEEE 802.11 use the following formula to compute the back-off related to each node:

$$Back\text{–}off = Rand[0, CW]*Slot\_Time, \quad CW_{min} < CW < CW_{max}$$

In order to compute the value of back-off for each node in this proposed algorithm, the rate of collision in the network besides the smallest CW must be taken into account. Thus, to compute the back-off, the equation (4) is proposed.

$$Back\text{–}off = Rand[0, (2^r + R_{col}) * CW_{min}] * Slot\_Time \quad (4)$$

Back-off_Time()

{

Get minimum CW(CW_{min}) from network layer.

Calculate Back-off time according to

$$Back\text{–}off = Rand[0, (2^r + R_{col}) * CW_{min}] * Slot\_Time$$

}

Where R_{col} denotes the collision rate between a station's two successful frame transmissions and r is a positive number.

By applying Eq. (4), all flows dynamically manage their contention parameters to meet their own QoS needs. A real-time flow that did not get its required QoS in the past due to competition from other flows decreases its contention window size so that statistically it will have a higher chance to obtain the channel in the future(Eq.(1),(2)). A best effort flow, on the other hand, increases its contention window size when the network is considered busy and hence releases the channel to the real-time flows(Eq.(3)). The random generated back-off counter ensures that the channel access attempts from different flows are spread out and do not cause a lot of collision. More importantly with attention to flow's current status, traffics with same class will have different back-off value when collisions occur. Specifically, after a collision occurs, low priority traffic will back-off for longer, and subsequently high priority traffic will have a better chance of accessing the channel. Contrary to [12], [15], in our proposed algorithm, no piggy-backed schedule information and neighborhood scheduling tables are needed. Therefore, there is no control message overhead imposed by our proposed algorithm.

In next section, the correct function of the proposed algorithm is proved.

3- Model Validation

In this section, we study the behavior of a single station with a Markov model, and we obtain the stationary probability π that the station transmits a packet in a generic (i.e., randomly chosen) slot time.

Bianchi uses a two-dimensional Markov chain of m + 1 back-off stages in which each stage represents the back-off time counter of a node, see Figure 2. A transition takes place upon collision and successful transmission, to a "higher" stage (e.g., from stage i− 1 to stage i in Figure 3) and to the lowest stage (i.e., stage 0) respectively.

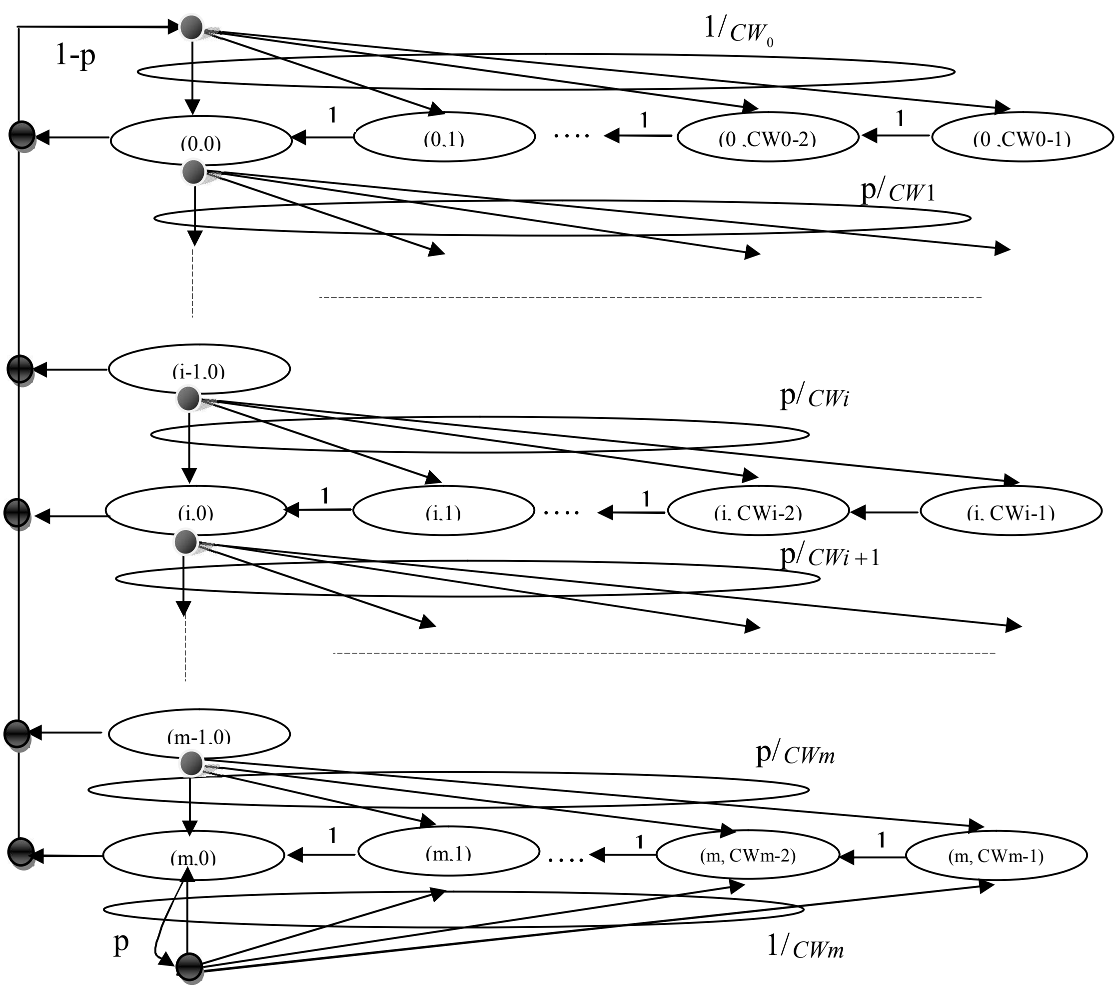

Figure 2. Markov chain model of back-off window size

Each state of this bi-dimensional Markov process is represented by {s(t),b(t)} , where b(t) is the stochastic process representing the back-off time counter for a given station and s(t) is the stochastic process representing the back-off stage (0,1,· · · ,m) of the station at time t. This model assumes that in each transmission attempt, each packet collides with constant and independent probability p. In other words, p is the probability that, in a slot time, at least one of the N − 1 remaining stations transmits as well. If at steady state each remaining station transmits a packet with probability π , p can be written as:

$$p = 1-(1-\pi)^{N-1} \tag{5}$$

Let $\begin{cases} b_{i,k} = \lim_{t\to\infty} P\{s(t)=i, b(t)=k\} \\ , i \in (0,m), k \in (0, CW_i - 1) \end{cases}$ be the stationary distribution of the chain. A transmission occurs when the back-off time counter is equal to zero. Thus, we can write the probability that a station transmits in a randomly chosen slot time as:

$$\pi = \sum_{i=0}^{m} b_{i,0} \tag{6}$$

For the above Markov chain, it is easy to obtain a closed-form solution for $b_{i,0}$ as a function of p. First, we can write the stationary distribution of the chain for $b_{i,0}$, $b_{m,0}$ and $b_{i,k}$:

$$\begin{cases} b_{i,0} = p^i b_{0,0} & 0 < i < m \\ b_{m,0} = \dfrac{p^m}{1-p} b_{0,0} & \\ b_{i,k} = \dfrac{CW_i - k}{CW_i} b_{i,0} & 0 \le i \le m, 0 < k < CW_i - 1 \end{cases} \tag{7}$$

The first and second expressions in (7) account from the fact that $b_{i-1,0} \times p = b_{i,0}$ *for* $0 < i < m$ and $b_{m-1,0} \times p = (1-p) b_{m,0}$. The third equation can be obtained considering the fact that $\sum_{i=0}^{m} b_{i,0} = \dfrac{b_{0,0}}{1-p}$ and taking the chain regularities into account (for $k \in (1, CW_i - 1)$) , that is:

$$b_{i,k} = \frac{CW_i - k}{CW_i} * \begin{cases} (1-p)\sum_{j=0}^{m} b_{j,0} & i = 0 \\ p \times b_{i-1,0} & 0 < i < m \\ p \times (b_{m-1,0} + b_{m,0}) & i = m \end{cases} \tag{8}$$

By imposing the normalization condition and considering Equation (7), we can obtain $b_{0,0}$ as function of p:

$$1 = \sum_{i=0}^{m} \sum_{k=0}^{CW_i - 1} b_{i,k} = \sum_{i=0}^{m} b_{i,0} \sum_{k=0}^{CW_i - 1} \frac{CW_i - k}{CW_i} =$$

$$\sum_{i=0}^{m} b_{i,0} \frac{CW_i + 1}{2} = \sum_{i=0}^{m} b_{i,0} \frac{2^i W_{\min} + 1}{2}$$

$$= b_{0,0} \frac{W_{\min} + 1}{2} + \sum_{i=0}^{m-1} (b_{0,0} p^i (\frac{2^i W_{\min} + 1}{2})) + (\frac{b_{0,0} p^m}{1-p})(\frac{2^m W_{\min} + 1}{2}) = \tag{9}$$

$$\frac{b_{0,0}}{2}\left[W_{\min} + 1 + \sum_{i=0}^{m-1} ((2p)^i W_{\min} + p^i) + \frac{p^m}{1-p}(2^m W_{\min} + 1)\right]$$

$$= \frac{b_{0,0}}{2}\left[W_{\min}(\sum_{i=0}^{m-1} (2p)^i + \frac{(2p)^m}{1-p}) + \frac{1}{1-p}\right]$$

Thus $b_{0,0}$ can be written as:

$$b_{0,0} = \frac{2(1-2p)(1-P)}{(1-2p)(W_{\min}+1) + pW_{\min}(1-(2p)^m)} \tag{10}$$

Finally, considering equations (6), (7) and (10), the channel access probability π of a node is derived as a function of the number of back-off stage levels m, the minimum contention window value $W_{\min}$, and the collision probability p:

$$\pi = \sum_{i=0}^{m} b_{i,0} = \frac{b_{0,0}}{1-p} = \frac{2(1-2p)}{(1-2p)(W_{\min}+1)+pW_{\min}(1-(2p)^m)} = \frac{2}{1+W_{\min}+pW_{\min}\sum_{k-0}^{m-1}(2p)^k} \quad (11)$$

Considering equation 11, how a node obtains a channel and transmits a flow depends upon the rate of collision and CW in each node. That is to say, any node that faces less collision and has the smallest CW obtains the channel with high probability and embarks upon the transmission of its flows. For this reason, nodes can regulate the CWs related to their own flows and provide the desirable QoS. In the proposed, the CW related to the flows is regulated by means of Eq. (1,2,3). These algorithms are regulated such that they will increase its CW value quickly and provide other flows with the resources existing in the system if a flow obtains a resource more than the required resource at a time and obtains a QoS higher than the desirable QoS. Consequently, other flows will not face any limitations in obtaining resources. On other hand, any node which does not obtain it required resources and QoS at a point in time make much efforts to obtain the resources and compensate for the damages by decreasing its own CW and acquiring much back-off in order to obtain its desirable QoS.

Therefore, it is seen that the algorithm proposed in this paper shows a correct function in different conditions, in this algorithm, the flows help each other under some circumstances besides quarreling with each other for obtaining resources in order for all the flows in the network to obtaining required QoS.

4- Discussions

In this paper we introduce a new QoS support protocol that could be run in large-scale ad hoc networks, which this protocol is simple, fully distributed and use no control packets. An important benefit of this protocol is that it does not need resource reservation and therefore, it does not have the problems related to the use of in-bound and out-bound signals to reserve and free the resources, and the network bandwidth is not occupied by reserving and freeing the resources. This has caused this protocol be a light weight protocol that could be used in multi-hop ad hoc networks.

In the future, we will investigate the effect of different values α, β, f, r on the throughput and delay related to different classes.

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