

# Providing Guaranteed Delay in Distributed Multimedia Wireless Packet Networks

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**Abstract.** The multimedia ad hoc wireless network is quite an attractive issue since it offers a flexible solution to enable delivery of multimedia services to mobile end users without fixed backbone networks. However, with the unique design challenges of ad hoc wireless networks, it is a non-trivial issue to provide bounded delay guarantee, with fair share of resources. In this paper, we implemented the delay guaranteed fair queueing (DGFQ) scheme distributively. From the results of performance evaluation, we can conclude that DGFQ also performs well to control bounded delay in multimedia ad hoc wireless networks.

*Index terms*— Fair queueing, Ad hoc network, Quality of Service (QoS), Multimedia network.

## 1 Introduction

There are a series of wireless technologies newly emerging, e.g., Mobile Ad hoc Network (MANET), Bluetooth and sensor networks. These emerging wireless technologies are also required to provide a set of applications, e.g., both error-sensitive and delay-sensitive applications, over the bandwidth-constrained wireless medium. To fulfill this requirement, the issue of providing fair and delay bounded channel access among multiple contending hosts over a scarce and shared wireless channel is essential. Fair queueing has been a popular paradigm to achieve this goal in both wireline and packet cellular networking environments [1]-[9].

However, the problem of designing fully distributed, scalable, and efficient fair scheduling algorithms in the shared-channel ad hoc wireless network remains largely unaddressed. In essence, the unique characteristics of ad hoc wireless networks such as location-specific contention create spatial coupling effects among flows in the network graph, and the fundamental notion of fairness may require non-local computation among contending flows. Adding these features together, fair queueing in shared-channel multihop wireless environments is no longer a

local property at each output link and has to exhibit global behaviors; this has to be achieved through distributed and localized decisions at each node.

In some related works the fair packet scheduling issues, on the aforementioned problems in ad hoc wireless networks, have addressed [10]-[12]. The focus of [10], [11] has been the problem formulation and an appropriate ideal centralized model for fair queueing in shared-channel multihop wireless networks. The proposed distributed fair scheduling implementation can at best conceptually approximate the centralized model. In [12], they devised distributed and localized solutions such that local schedulers self-coordinate their local interactions to achieve the desired global behavior. They also propose a suite of fully distributed and localized fair scheduling models that use local flow information and perform local computations only. Though the contributions stated above, [12] mainly addressed on the fairness of the overall throughput performance for the various usage scenarios without consideration of the QoS factors such as delay performance especially for the multimedia wireless ad hoc wireless networks.

In [13], we propose a new fair queueing scheme i.e., delay guaranteed fair queueing (DGFQ), guaranteeing bounded delay of multimedia services. DGFQ scheme is basically a GPS based fair queueing scheme with some modifications to guarantee bounded delay. In detail, the *service differentiation coefficient* was introduced to apply additional weight factor for the delay guaranteed (DG) class over non-delay guaranteed (NG) class. With this policy, DGFQ provides better delay performance for DG class at the same fairness guarantee without serious increase of computational complex. However their work has focused on the centralized network, rather than distributed one e.g., ad hoc wireless networks.

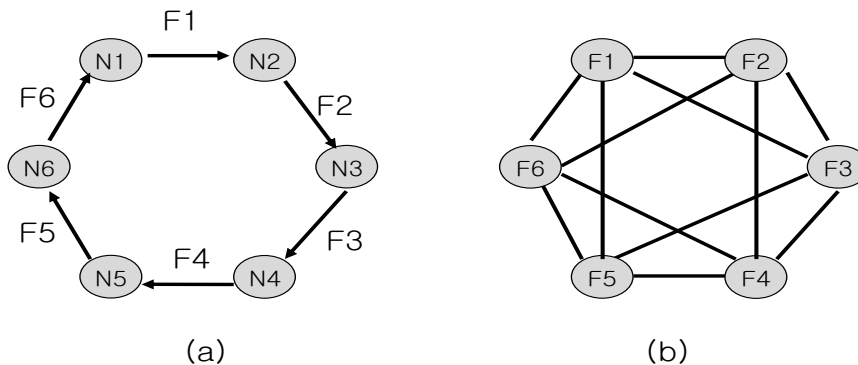
In this paper we implement the delay guaranteed fair queueing (DGFQ) [13] in the multimedia ad hoc wireless network using the distributed fair queueing protocol proposed in [12], to verify the controllability and adaptability of DFGQ on the bounded delay requirement in multimedia ad hoc wireless networks. From the results of performance evaluation, we can conclude that DGFQ also performs well to control bounded delay in multimedia ad hoc wireless networks

The rest of the paper is organized as follows. Section 2 describes the network model for ad hoc fair scheduling. Section 3 we describe on distributed implementation of delay guaranteed fair queueing (DGFQ) in the multimedia ad hoc wireless network. Section 4 presents a simulation-based performance evaluation of the implementation, and, finally in Section 5 we conclude our work.

## 2 System Model

### 2.1 Network Model

In this paper, we consider a packet-switched multihop wireless network in which the wireless medium is shared among multiple contending users, i.e., a single physical channel with capacity  $C$  is available for wireless transmissions. Transmissions are locally broadcast and only receivers within the transmission range of a sender can receive its packets. Each link layer packet flow is a stream of packets



**Fig. 1.** Node graph and flow graph in location dependent contention.  
(a) Original node topology graph (b) Flow graph

being transmitted from the source to the destination, where the source and destination are neighboring nodes that are within transmission range of each other. Two flows are contending with each other if either the sender or the receiver of one flow is within the transmission range of the sender or the receiver of the other flow [14]. We make three assumptions [14]-[18]: (a) a collision occurs when a receiver is in the reception range of two simultaneously transmitting nodes, thus unable to cleanly receive signal from either of them; we ignore capture effect in this work, (b) a node cannot transmit and receive packets simultaneously, and (c) neighborhood is a commutative property; hence, flow contention is also commutative.

In addition, we do not consider non-collision-related channel errors. For simplicity of presentation, we only consider fixed packet size in this paper, which is a realistic assumption in typical wireless networks. Our proposed models work equally well for the variable-packet-size case.

## 2.2 Flow Contention Graph

The flow contention graph is introduced to describe the contending flows in the network[12]. The flow contention graph precisely characterizes the spatial-domain, as well as the time-domain, contention relationship among transmitting flows. In a flow graph, each vertex represents a backlogged flow, and an edge between two vertex denotes that these two flows are contending with each other. If two vertices are not connected, these two flows can transmit simultaneously, thus spatial reuse is possible. Therefore, the flow graph explicitly describes which flows are contending and which flows can be concurrently transmitting.

As an example, Figure 1 shows the flow contention graph for the six flows in the node graph. Each node in an ad hoc wireless network maintains information

for flows within one-hop neighborhood in the flow contention graph. However, one hop neighborhood in a flow graph will translate to the two-hop neighborhood in the real node graph in practice. In Figure 1, one-hop neighborhood of flow  $F1$  includes  $F2, F3, F5, F6$ . Therefore, for given a flow  $f$ , it is required to maintain flow information for flows that are within the transmission range of either  $f$ 's sender or its receiver. However, for any given node, our goal is to maintain flow information (i.e., service tags) for flows only within its one-hop neighborhood in the node graph. That is, no node needs to be aware of flow information at nodes that are more than one hop away in the node graph.

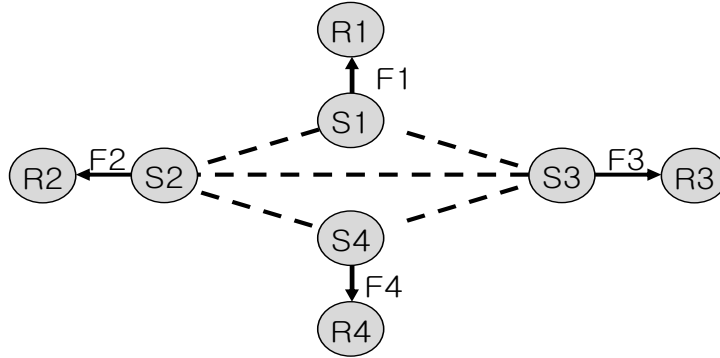


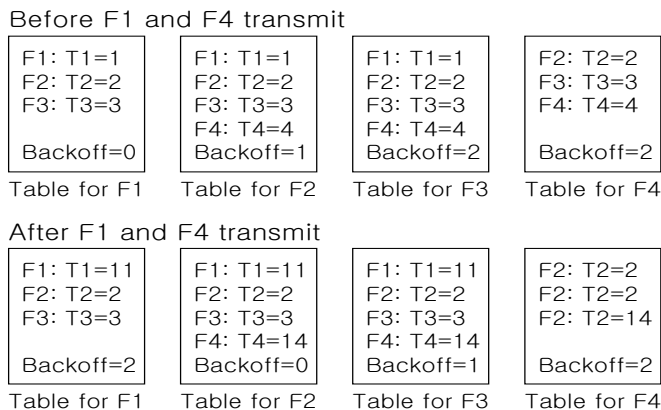
Fig. 2. Node graph of an illustrative example.

### 3 Distributed Implementation of DGFQ in Ad Hoc Wireless Networks

#### 3.1 Delay Guaranteed Fair Queueing (DGFQ)

In delay guaranteed fair queueing (DGFQ), two tags i.e., a start tag and a finish tag, are associated with each packet. Packets are scheduled in the increasing order of the start tags of the packets. Furthermore,  $v(t)$  is defined as the start tag of the packet in service at time  $t$ . Finally, we assume that, in DGFQ scheme, there is a certain interval of time in which all flows are scheduled at least once, we call it *scheduling interval*.

All flows are classified in to a number of classes according to their delay bound requirements. The simplest and basic classification is to make two classes, one for delay guaranteed (DG) flows and the rest for non delay guaranteed (NG) flows. In our scheme, we introduce the *service differentiation coefficient*,  $\alpha$  ( $0 < \alpha \leq 1$ ), to handle each flow classes differently. By varying  $\alpha$ , we can customize delay



**Fig. 3.** Table updates between transmission of flows 1 and 4.  
(assume packet transmission time = 10)

bound for individual flows i.e., adjust the relative service order of each flows in a scheduling interval.

The complete algorithm is defined as follows.

1. On arrival, a packet  $p_f^j$  is stamped with start tag  $S(p_f^j)$ , computed as

$$S(p_f^j) = \max\{v[A(p_f^j)], F(p_f^{j-1})\} \quad j \geq 1 \quad (1)$$

where  $F(p_f^j)$ , the finish tag of packet  $p_f^j$ , is defined as

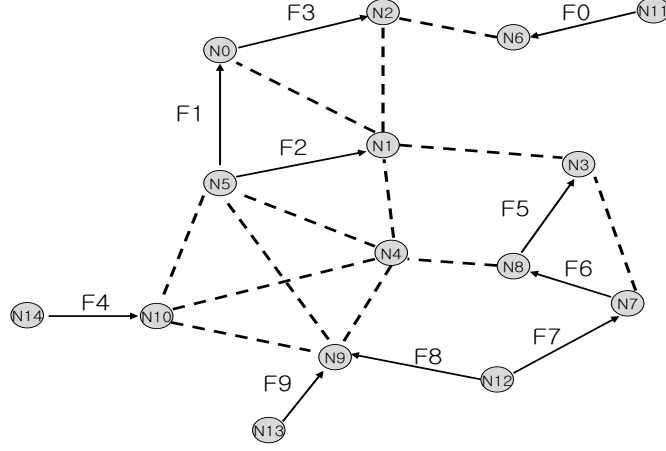
$$F(p_f^j) = S(p_f^j) + \alpha_f \frac{l_f^j}{\phi_f} \quad (2)$$

where  $F(p_f^0) = 0$  and  $\phi_f$  is the weight of flow  $f$  and  $\alpha$  ( $0 < \alpha_f \leq 1$ ) is the *service differentiation coefficient* for flow  $f$ .  $\alpha=1$  for NG class or appropriate value for DG class.

2. Initially the system virtual time is 0. During a busy period, the system virtual time at time  $t$ ,  $v(t)$ , is defined to be equal to the start tag of the packet in service at time  $t$ . At the end of a busy period,  $v(t)$  is set to the maximum of finish tag assigned to any packets that have been serviced by then.
3. Packets are serviced in the increasing order of the start tags; ties are broken arbitrarily.

### 3.2 Basic Scheduling Operations

The detailed operations for distributed implementation of delay guaranteed fair queueing (DGFQ) in multimedia ad hoc wireless network consist of the following four parts:



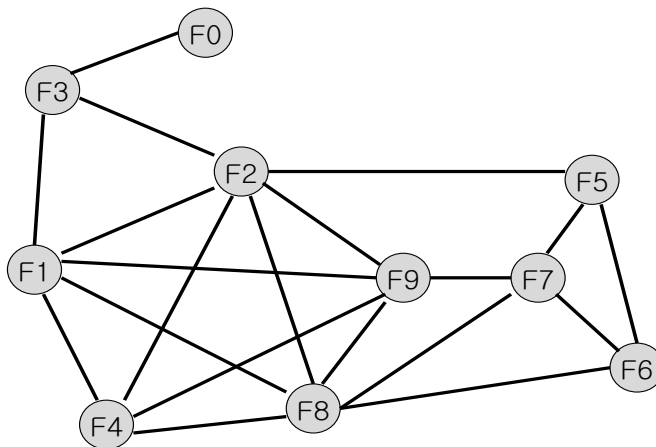
**Fig. 4.** Node graph of simulated multimedia ad hoc wireless network.

- *Local state maintenance:* Each node  $n$  maintains a local table  $E_n$ , which records each flow's current service tag for all flows in its one-hop neighborhood of the flow graph. Each table entry has the form of  $[f, T_f]$ , where  $T_f$  is the current service tag of flow  $f$ , e.g., the most recent start tag of flow  $f$ .
- *Tagging operations:* Two tags, i.e., a start tag and a finish tag, are assigned for each arriving packet, using DGFQ algorithm described in the previous section 3.1, for each flow  $f$  in the local table.
- *Scheduling loop:* After the tagging operation, at the sender node  $n$  of a flow  $f$ , the following procedure is performed, whenever the node  $n$  hears that the channel is clear,
  - (a) if the flow  $f$  has the smallest service tag in the table  $E_n$ , of node  $n$ , transmit the head-of-line packet of flow  $f$  immediately;
  - (b) otherwise, set the backoff timer  $B_f$  of flow  $f$  as

$$B_f = \sum_{g \in S} I(T_g(t) < T_f(t)) \text{ minislots,}$$

where  $I(x)$  denotes the indicator function, i.e.,  $I(x) = 1$ , if  $x > 0$ ;  $I(x) = 0$ , otherwise.

- (c) if flow  $f$ 's backoff timer expires and the channel is idle, transmit the head-of-line packet of flow  $f$ .
- *Table updates:* whenever node  $n$  hears a new service tag  $T'_g$  for any flow  $g$  on its table  $E_n$ , it updates the table entry for flow  $g$  to  $[g, T'_g]$ . Whenever node  $n$  transmits a head-of-line packet for flow  $f$ , it updates flow  $f$ 's service tag in the table entry.



**Fig. 5.** Flow graph of simulated multimedia ad hoc wireless network.

We provide an illustrative example to show how the algorithm works. In the example, as shown in Figure 2, four flows are scheduled from the sender node to its respective receiver node and the dotted line denotes the two nodes are within the communication range. It is assumed that the initial virtual time  $V = 0$ , and the initial service tags for the four flows are  $T_1 = 1, T_2 = 2, T_3 = 3, T_4 = 4$ . The table maintained at each sender of the four flows and the backoff calculation and table updates before and after transmission of flows 1 and 4 are shown in Figure 3.

### 3.3 Protocol Description

In the distributed implementation protocol, each data transmission follows a basic sequence of RTS-CTS-DS-DATA-ACK handshake, and this message exchange is preceded by a backoff of certain number of minislots. When a node has a packet to transmit, it waits for an appropriate number of minislots before it initiates the RTSCTS handshake. Specifically, the node checks its local table and sets a backoff timer for flow  $f$  to be the number of flows with tags smaller than the tag of flow  $f$ . This way, the local minimum-tag flow backs off for zero minislot and contends for the channel immediately. If the backoff timer of  $f$  expires without overhearing any ongoing transmission, it starts RTS carrying  $B_f^R$ , the backoff according to the table at the receiver's side, to initiate the handshake. If the node overhears some ongoing transmission, it to initiate the handshake. If the node overhears some ongoing transmission, it cancels its backoff timer and defers until the ongoing transmission completes; In the meantime, it updates its local table for the tag of the on-going neighboring transmitting flow. When other nodes hear a RTS, they defer for one CTS transmission time

to permit the sender to receive a CTS reply. When a receiver receives a RTS, it checks its local table. If  $B_f^R$  is greater than or equal to the backoff value for flow  $f$  in the receiver's local table, it responds with CTS. Otherwise, the receiver simply drops RTS. This procedure is required for maintaining the table information at both sender and receiver nodes. Detailed mechanism descriptions are given in [12]. Once a sender receives the CTS, it cancels all remaining backoff timers (for other flows) and transmits DS. When hosts hear either a CTS or a DS message, they will defer until the DATA-ACK transmission completes.

In order to propagate a flow's service tag to all its one-hop neighbors in the node graph and reduce the chance of information loss due to collisions during this service tag information propagation, the tag  $T_f$  for flow  $f$  is attached in all four packets RTS, CTS, DS and ACK, i.e., the *old tag* in RTS and CTS packets, and *updated tag* in DS and ACK packet.

## 4 Performance Evaluation

### 4.1 Simulation Environment

We use simulations to evaluate the performance our distributed implementation of DGFQ in multimedia ad hoc wireless networks. The following is the simulation environment used in this simulation.

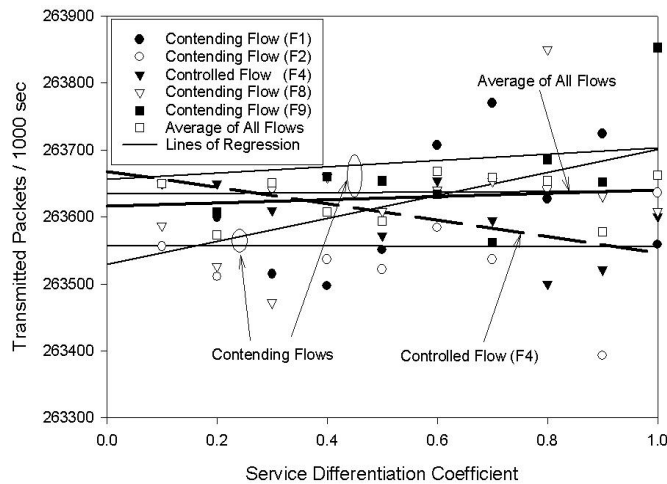
The radio model is based on existing commercial wireless network with a radio transmission range of 250 meters and channel capacity of 2Mbit/sec which is typical capacity of current wireless mobile networks. Moreover, for the distributed implementation of DGFQ scheme, error free channel model is assumed to concentrate our evaluation work on the key features of proposed scheme, i.e., the controllability and adaptability of DGFQ scheme in distributed network environment such as multimedia ad hoc wireless networks to provide delay guaranteed service.

As the traffic source model, we choose the modified MPEG source, described in [19]. Moreover, we assumed that all the sources have identical characteristics. In this video flow is model, there are three types of frame, i.e., I, B and P frames. Each frame size is determined by a Lognormal distribution with a specified mean and standard deviation. A video source generates 24 frames per second.

Further, we adopt the simulation scenario 3 used in [12], which includes 14 nodes transmitting 10 flows, because it is a reasonable scale considering our target environment of multimedia ad hoc wireless networks. Figures 4 and 5 shows the node graph and flow graph of simulated network respectively. More specifically, flow  $F4$  is controlled with the aforementioned *service differentiation coefficient*,  $\alpha$ , to testify the controllability of DGFQ for guaranteed delay provision in distributed network environment. In addition, the simulation results for flow  $F4$  are compared with that of other contending flows and overall average.

Finally, each simulation is run for 1000 seconds, and we selected average delay, maximum delay and throughput as the performance measures as in [13]. Detail definitions and discussions for these measure are described in the following section 4.2.

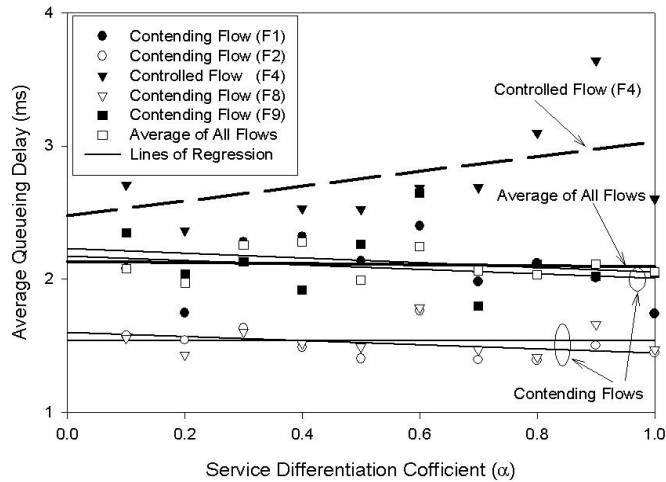
## 4.2 Results and Discussions



**Fig. 6.** Total transmitted packets with varying the value of *service differentiation coefficient* ( $\alpha$ ).

**Throughput** We used *throughput* as a fairness measure, which is total transmitted packets during the whole simulation duration, say, 1000 seconds. Figure 6 shows the throughput of flows with scattered points and its regression. As reported in [13], basically there is only a minor differences in throughput between flows either controlled ( $F4$ ) or not (all other flows). In the figure, thick solid line represents the average throughput of all flows, and thick dashed line shows the throughput of the controlled flow ( $F4$ ). Specifically, the number of transmitted packets is inverse proportional to  $\alpha$ , it is because  $\alpha$  controls  $F4$  with the share of channel in some extend, and, subsequently, it affects to the throughput of contending flows. It also be also notice that it is possible to control individual flow with varying  $\alpha$ .

**Average delay** In our work *average delay* is defined as the average time interval between the arrival and departure of a packet for a certain time duration. As shown in the Figure 7, the *differentiation coefficient*  $\alpha$  is the key parameter to manage delay performance. Again, in the figure, thick solid line represents the overall average delay, averaged for all flows, and thick dashed line shows the average delay of the controlled flow ( $F4$ ). With varying  $\alpha$  we can control the



**Fig. 7.** Average delay with varying the value of *service differentiation coefficient* ( $\alpha$ ).

average delay of flow  $F4$ . On the other hand, contrary to the throughput case, discussed above, delay is proportional to  $\alpha$ .

**Maximum delay** The *maximum delay* is another critical performance measure for real time multimedia flows. We define maximum delay as the maximum interval between the arrival and departure of a packet in the system in a certain duration of time, say, simulation duration. We can get the results simultaneously with average delay from the same simulation. As in the previous figures, in Figure 8, thick solid line represents the overall maximum delay, averaged for all flows, and thick dashed line shows the maximum delay of the controlled flow ( $F4$ ). From the Figure 8, we can conclude that maximum delay could be also controllable with  $\alpha$ , which means DGFQ controls the maximum delay also in distributed networks.

## 5 Conclusion

We implemented a delay guaranteed fair queuing scheme, DGFQ[13], distributively in the multimedia ad hoc wireless network environment. As far as throughput is concerned, there is only a minor differences in throughput between flows either controlled by *service differentiation coefficient* ( $\alpha$ ) or not. For delay performance either average delay or maximum delay, from the simulated results, they are inversely proportional to the value of  $\alpha$ , i.e., they are controllable with

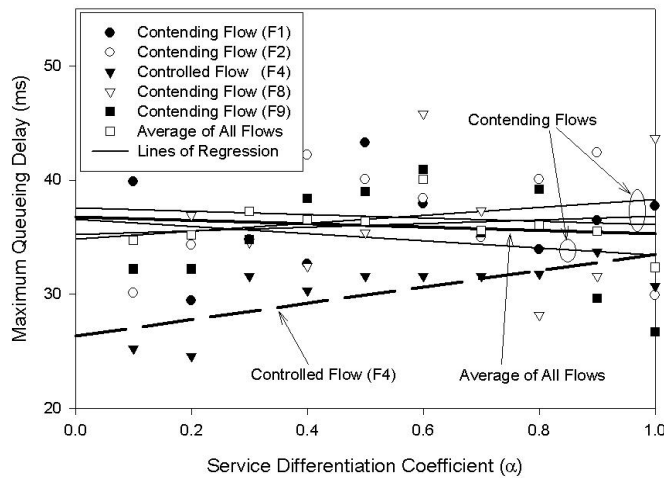


Fig. 8. Maximum delay with varying the value of *service differentiation coefficient* ( $\alpha$ ).

our implementation. In summary, the controllability and adaptability of DGFQ on the multimedia traffic in the distributed network environment was verified.

We just consider about a limited network environment, i.e., stationary nodes with error-free wireless channel, which is too idealistic to apply our work in the practical systems. So, much more work should be done for the dynamic topology variation by mobile nodes in error-prone wireless channel case as a future work.

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