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Improving the Performance of QoS Models in MANETs through Interference Monitoring and Correction

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Abstract

Mobile Ad hoc Networks (MANETs) have been proposed for a wide variety of applications, some of which require the support of real time and multimedia services. To do so, the network should be able to offer quality of service (QoS) appropriate for the latency and throughput bounds to meet appropriate real time constraints imposed by multimedia data. Due to the limited resources such as bandwidth in a wireless medium, flows need to be prioritised in order to guarantee QoS to the flows that need it. In this research, we propose a scheme to provide QoS guarantee to high priority flows in the presence of other high as well as low priority flows so that both type of flows achieve best possible throughput and end-to-end delays. Nodes independently monitor the level of interference by checking the rates of the highest priority flows and signal corrective mechanisms when these rates fall outside of specified thresholds. This research investigates using simulations the effects of a number of important parameters in MANETs, including node speed, pause time, interference, and the dynamic monitoring and correction on system performance in static and mobile scenarios. In this report we show that the dynamic monitoring and correction provides improved QoS than fixed monitoring and correction to both high priority and low priority flows in MANETs.

1. Introduction

Mobile ad hoc networks (MANET) [1] consist of wireless nodes that communicate with each other by cooperatively sharing a common wireless medium. These networks operate without infrastructure to create and maintain a communication topology that could be useful in a number of applications such as military, emergency relief and sensor networks enabling data exchange between hosts in absence of a centralized fixed infrastructure or to form a temporary network [2]. Mobile ad-hoc networks (MANETs) enable mobile users to communicate without the use of a fixed infrastructure. These networks can be used, e.g., to extend the range of access points, to allow communication in disaster areas or to realize inter-vehicle communications.

2. Quality of Service (QoS) in MANETs

With the widespread availability of portable computing devices, more and more applications are being designed for mobile use especially for multimedia applications such as streaming audio, games and real-time data such as stock exchange data analysis [3]. This evolution makes QoS in MANETs relevant and important and poses a new challenge to the research community.

RFC 2386 [4] characterises QoS as "*a set of service requirements to be met by the network while transporting a packet stream from source to destination*". ITU-T[1] defines QoS as "*the collective effect of service performance which determines the degree of satisfaction of a user of the service*" [5].

QoS is required in order to provide a better service to certain flows that require measurable pre-specified parameters covering network delay, delay variance (jitter), available bandwidth, and probability of packet loss. Moreover, most existing routing protocols developed for MANETs such as AODV [6], DSR [7] and ZRP [8], have been designed primarily to carry best-effort traffic, whose focus is to provide connectivity between the nodes and not to support QoS.

Several QoS models has been proposed for MANETs in the previous works such as *INSIGNIA* [9], *ASAP* [10], *SWAN* [11, 12, 13], *(E-SWAN)* [14], *FQMM* [15][16] and *LWQ* [17]. The main purpose of a QoS model is to define the methodology by which certain types of services (e.g. per-flow or per-class) could be provided in the network [18] along with service differentiation [19] where multimedia flows such as voice or video are given priority over best effort flows (e.g.: file transfer, e-mails). In the bandwidth-constrained MANET environment shared resources must be carefully allocated across traffic flows. Differing traffic flows have differentiated resource requirements and differentiated costs for not

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[1] ITU - a telecommunication standardization body.

receiving desired resources. A first step in providing optimal resource allocation across all traffic flows is then to differentiate traffic flows according to requirements and priority. However, none of these models provides strict guarantee and monitor the interference occurred to high priority flows like LWQ.

3. Interference

There are two potential sources of interference to the high priority flows in the network.

3.1. Direct Range Interference (DRI) Nodes

These nodes are within the reception range of the node carrying high priority traffic. Some of these nodes may be carrying medium priority or low priority traffic which reduces the bandwidth available to the high priority flow. Being in the direct reception range, these nodes can be informed relatively easily of the interference by broadcasting a message and corrective action can be taken quickly. These nodes are subsequently called as DRI Nodes.

3.2. Nodes Outside Direct Transmission Range but within Interference Range

These nodes are within the interference range of the H-Node, but not in reception range. Thus, transmissions from these nodes interfere with the transmissions and receptions of H-Flow. In a random ad hoc network topology with random connections, it is likely that the prevention of interference from the DRI nodes is not sufficient to restore the rate of the H-Flow. It may be required to stop any interfering flows within these nodes. It is not straightforward to inform these nodes of the interference. Some of these nodes may be multiple hops away from the nodes carrying H-flow. Broadcasting a message to nodes two hops away may reach some of these interfering nodes, not necessarily all. However, as the control packet travels in an expanding ring, a 2 hop control packet may cause too many flows to stop, resulting in an exorbitant underutilization of the network resources. In our definition of corrective mechanisms, we assume that the network is sufficiently dense so that stopping interference caused by nodes in direct range is sufficient to restore the resource availability of the H-flow.

4. LWQ QoS Model

Light-weight QoS (LWQ) is a QoS model that attempts to provide improved QoS to flows of a highest priority class by taking into account the interference of high priority flows. From all of the previous QoS models, none of them tried to provide required and sufficient QoS guarantee to high priority flows.

In this research, we present and evaluate novel mechanisms to provide improved QoS to the highest priority traffic flows. These mechanisms do not require any central coordination and do not depend on any specific protocols at the physical, MAC, or network layers. In our proposed scheme, nodes independently monitor the rates of the highest priority flows and signal corrective mechanisms when these rates fall outside of specified local bounds. Triggering conditions for network-wide corrective mechanisms are designed to trade-off rapid reactive response to local QoS violations with control packet overhead. A range of corrective mechanisms are explored that attempt to maintain reactive response while improving total network utilization, including resources consumed by lower priority traffic. Corrective mechanism is explained in the section below.

4.1. Monitoring and Correction

The primary focus of this research is on providing improved QoS to flows of highest priority class, a feature absent in existing QoS models for MANETs. We assume that the flows of this class have clearly defined traffic characteristics such as packet rate and packet size. The model must ensure that each of the high priority flows is able to maintain these characteristics for the lifetime of connection. All such flows must therefore be monitored at each node through which they pass. Any divergence from the designated packet rate, for example, must trigger a corrective action by the node detecting it. A node take corrective action by sending a squelch packet to the flows that interfere with the high priority flows so that the low priority flows will be dropped and stop transmitting. Therefore after this corrective action the packet rate of the low priority flows can be restored at the original rate it is sent. We need to define elaborate mechanisms to monitor the activity of each high priority flow. The model also requires mechanisms that define how a corrective action needs to be taken to adjust any interfering flows affecting the resources of a high priority flow.

4.2. Advantages of LWQ

LWQ has been in a number of research studies that has a number of advantages which include:

i. LWQ has been shown in [17] to be able to maintain better QoS guarantees for the high-priority flow in terms of packet rate and high-priority throughput compared to INSIGNIA and DIFFSERV.
ii. Use a probability of dropping of low priority flows instead of suppressing all of the low priority flows.
iii. LWQ is stateless QoS model that has an advantage of classifying flows into real-time and best-effort class. In this study, we define the real-time flows (e.g. audio) as high priority flows and none real-time traffic (e.g. file transfer) as low priority flows.

4.3. Illustration

The illustration is displayed in Fig. 1. For example, suppose that there is a continuous high priority flow from $s1$ to $d1$. When operating alone, its flow-rate is fixed at a predefined value. Now, a low priority flow $s2$ - $d2$ starts. Let us assume that we want to fix and maintain this high priority flow rate at a predefined level. However, since these two routes (Fig. 1) are close enough to cause direct range interference (DRI) nodes, they interfere with each other, which leads to a reduction in the rate of high-priority flow at the H-Node. H-Node is the first node along the path of highest priority flow which can receive packets of high priority flow at the desired rate but cannot transmit at the same rate because of interference from transmissions of low priority flows. Our objective is to detect this reduced flow rate of high priority flow at H-Node due to the presence of low-priority flow and back propagate this knowledge back to the source of the low priority flow, which then can adaptively reduce its flow rate to maintain the high priority flow rate at its derived level.

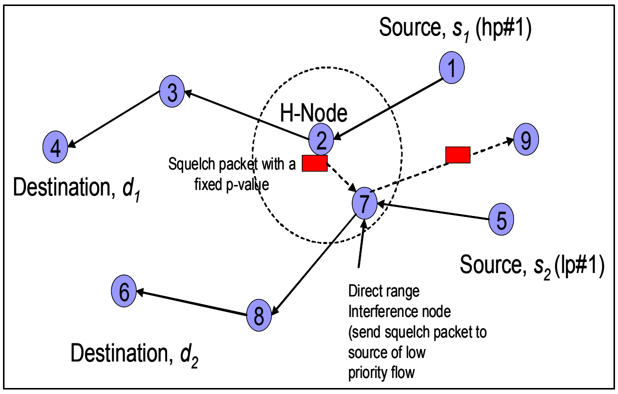

Figure 1. Low priority flow (*s2*-*d2*) is creating interference with high priority flow (*s1*-*d1*) due to direct range interference

Figure 2 below shows the algorithm of fixed p-value.

4.4. Algorithm of the Fixed P-value

Algorithm 1: Fixed p-value

```
→ Probabilistically select node that must take corrective action by using fixed p-value
  H-Node is able to receive $r_{th}$ packets (e.g. 60 packets) but unable to transmit $t_{th}$ packet (e.g.: 55 packets)
  $r_{th} \leq r \cdot w,\ t_{th} \leq r \leq w$ and $t_{th} \leq r_{th},$. where: $r_{th}$ is the receiving threshold, $t_{th}$ is the transmitting threshold
  H-Node on detecting interference
    Broadcast Squelch packet with a fixed p-value to DRI
    DRI send Sq packet to source node, for the next 5 seconds after receiving Sq, drop all packets it carries (whether such as relays or source) to ensure source node receive Sq packet
    On receiving Sq packet, source node stop generating packets
```

Figure 2. A Description of LWQ fixed p-value algorithm

Despite having some guarantees to high-priority packets, the LWQ architecture can cause a reduction in the total throughput because of the corrective action taken by one-hop neighbours to stop transmission of other lower priority flows in attempt to maintain the rate of high-priority flows. As a result, this scheme leads to underutilisation of network resources [17].

4.5. Algorithm of the Dynamic P-value

The current version of LWO model with the fixed threshold, however, does not take into account the level of severity of the interference experienced by the high priority flows. In this research, we propose the dynamic threshold to the high priority flows. As more high priority flows enter the network, a node that carries high priority flows need to be more sensitive and responsive to the level of interference. This would make the high priority flows achieve their QoS requirements because they can avoid the interference from the low priority flows early.

We propose an improvement of this technique by adjusting the *p-value* based on the difference between the number of packets transmitted within the monitoring window and the maximum number of packets that could be transmitted within the same window. Figure 3 describe the algorithm of the dynamic p-value. In dynamic p-value algorithm, a large negative difference between the two values indicates the presence of high interference and thus a low *p-value* so that the probability of low priority flows to stop is high. This results in a large number of nodes taking corrective actions. If the interference is low, the p-value will be high, and so a smaller number of nodes take a corrective action. The *p-value* is directly proportional to the difference or the *error* as proposed by dynamic p-value in the following algorithm, outlined in Fig. 2.

Algorithm 2: Dynamic P-value

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→ To probabilistically select node that must take corrective action by using dynamic p-value according to the level of interference (mild or severe interference):
H-Node on detecting interference
Get the number of packet received ($r_{th}$);
Get the number of packet sent ($t_{th}$);
If packet $m$ received for the first time then
    If $r_{th} \underset{\cdot}{\geq} r_{high}$ & $t_{th} \geq t_{low},$ then
        Node has a mild interference: mild correction,
        -> high p-value $p = p1$ ;
    Else $r_{th} \underset{\cdot}{\geq} r_{high}$ & $t_{th} \leq t_{low}$
        Node has a severe interference -> aggressive correction -> low p-value $p = p2$ ;
    End_if
End_if
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```
    Generate a random number RN over [0, 1].
    If RN ≥p-value, nodes take corrective action;
otherwise, no correction
```

Figure 3. A Description of LWQ dynamic p-value algorithm

Table I. Simulation parameters for the LWQ QoS model

Simulation Parameter	Value
Number of nodes	50
Simulation area	1500 x 300
Number of high-priority flows	3
Packet length and packet interval	80 byte, 32 packets/sec
Rate of high-priority flows	20 kbps
Number of low-priority flows	13
Packet length, packet interval	800 byte, 20 packets/sec
Rate of low-priority flows	128 kbps
Node mobility	5, 20 m/s
Pause time	0 sec (mobile scenario), 900 sec (static scenario)
Simulation time	900 sec
Routing protocol	AODV
MAC protocol	IEEE 802.11

Table I shows the simulation parameters used in our experiments. The simulation has 50 nodes which are randomly distributed in 1500x300 meter area. The rate of high priority flows is set to 20kbps (e.g. audio file), whereas the rate of low priority flows is set to 128kbps to correspond the file-transfer (ftp) application. The simulation is tested in two scenarios; mobile scenarios and static scenarios. In mobile scenarios, all nodes move throughout the simulation time whereas in static scenario, none of the nodes move. Nodes moves using random way-point model.

In order to trigger the corrective action after detecting interference, the number of low priority flows is set to 13. This number is chosen because the network has been found to starts to saturate at this level. This allows us to evaluate the performance of our model under high-traffic conditions. The high priority flows is range from 1 to 3.

We have compared the dynamic p-value (in which the p-value is set according to the level of interference) and the two versions of the fixed p-value. The two versions of the fixed p-value have been used to evaluate the performance at one situation at a time when nodes only take a corrective action at either only low interference or high interference.

Figure 4 and 5 show that adjusting the p-value at p-value of 0.5 as low p-value and 0.7 as high p-value significantly shows the best p-value to throughput and end-to-end delay of high and low priority flows respectively in the scenario of 50 nodes and maximum speed 20 m/s and 0 pause time. These p-value values are then being used to provide the dynamic range between high threshold and low threshold for the dynamic p-value algorithm.

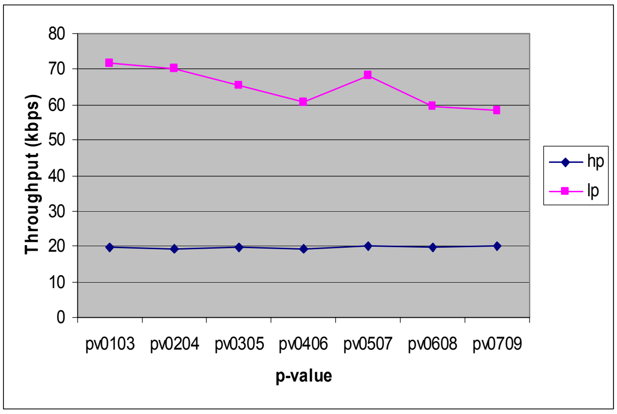

Figure 4. Throughput of HP and LP flows vs. p-value

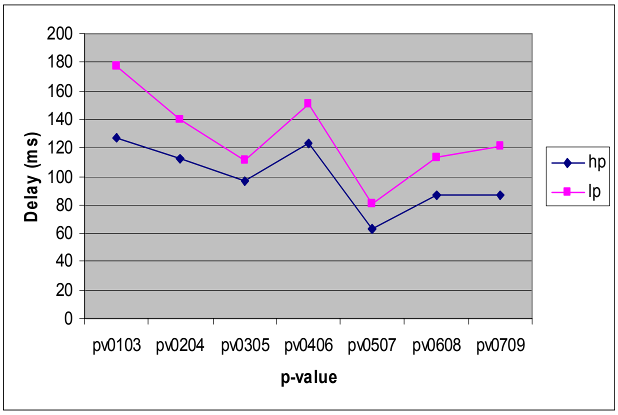

Figure 5. End-to-end delay of HP and LP flows vs. p- value

5. Impact of the dynamic p-value on the performance of LWQ

We have run simulation on static and mobile scenarios. In static scenarios, all nodes do not move at all and in mobile scenarios, all nodes moves (e.g.: pause time 0 s). In mobile scenarios, we have run simulation with low mobility (5 m/s) and high mobility (20 m/s).

5.1. Static Scenarios

We have used the static scenario in an attempt to minimise the tendency of interference from collision and congestion in the network as all nodes do not move.

Figure 6 shows the achieved throughput of high priority (HP) improves a little and comparatively equal for low priority (LP) flows using dynamic compared to fixed p-value. Figure 7 however shows that the end-to-end delay of both HP flows and LP flows improves significantly for the dynamic p-value compared to the fixed p-value. The end-to-end delay of HP and LP flows using the fixed p-value also does not satisfy the requirement of QoS bounded delay of below 300 ms.

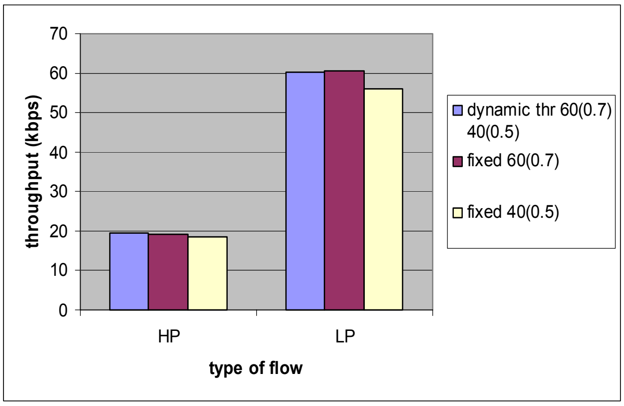

Figure 6. Throughput of high (HP) and low priority flows (LP) in static scenario

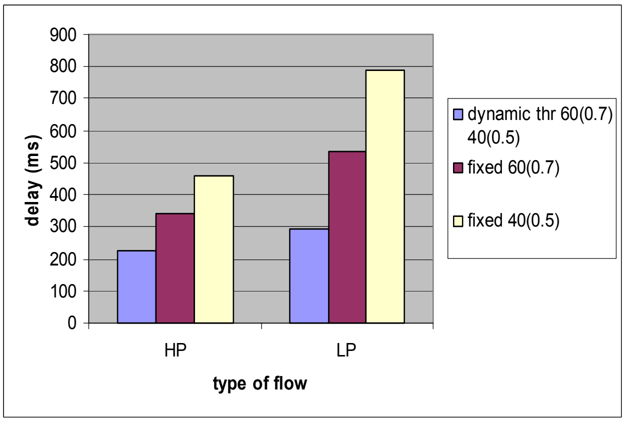

Figure 7. End-to-end delay of high (HP) and low priority flows (LP) in static scenario

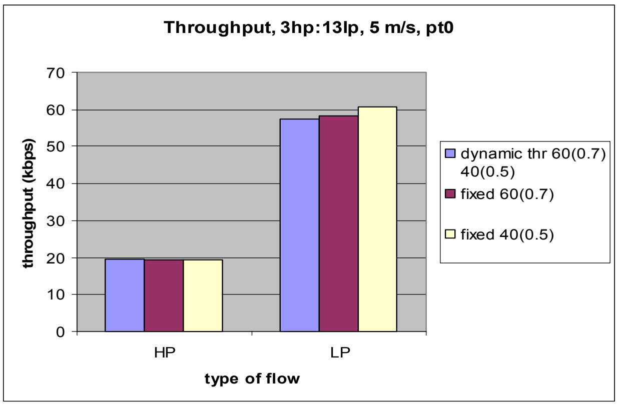

Figure 8. Throughput of high (HP) and low priority flows (LP) at 5 m/s in mobile scenario

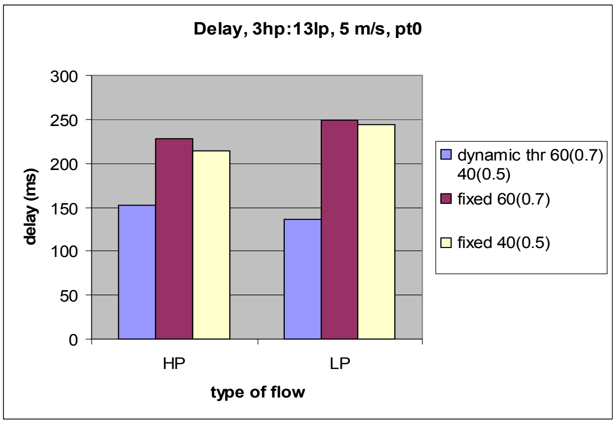

Figure 9. End-to-end delay of high (HP) and low priority flows (LP) at 5 m/s in mobile scenario

5.2. Mobile Scenarios

In mobile scenarios, nodes tend to come in close transmission range of each other, and as a result more direct range interference frequently occurs in the network.

Figure 8 and 9 depict the results for low mobility (5 m/s). Figure 8 shows that the throughput of high priority (HP) improves a little and equally effective for low priority (LP) flows using the dynamic p-value compared to the fixed p-value at low mobility.

Figure 9 shows that the end-to-end delay of both HP flows and LP flows improves significantly for the dynamic p-value compared to fixed p-value. The end-to-end delay of HP and LP flows using the dynamic p-value is 50% lower in the mobile scenario than the end-to-end delay in static scenario. This shows that in mobile scenario where nodes are moving, the end-to-end delay improves compared to when nodes are static while transmitting the flows. Figure 9 also shows that the end-to-end delay of HP flows is 30% improvements and 50% improvement for LP flows compared to the fixed p-value.

Figure 10 and 11 depicts the results for high mobility (20 m/s). The throughput and end-to-end delay improves when using the dynamic p-value. The dynamic p-value leads to 50% improvement than using the fixed p-value for the end-to-end delay of both HP and LP flows. It also can be seen that at high speed the end-to-end delay in the case of the dynamic p-value is lower than that in low speed (5 m/s). This shows that as nodes moves fast the end-to-end delay improves compared to when the nodes moves slower because as the nodes moves faster the possibility for the flows to reach the destination faster is higher.

The improvements of the dynamic p-value can be seen significantly especially in the end-to-end delay of LWQ. Dynamic p-value monitors the interference to high priority flows according to the level of interference; low or high interference. Therefore low priority flows are less dropped if the interference is low; making the low priority flows to continue until it reach the destination otherwise it has to re-initiate its flows to re-start sending after a duration of time which will then increase the end-to-end delay of the flows.

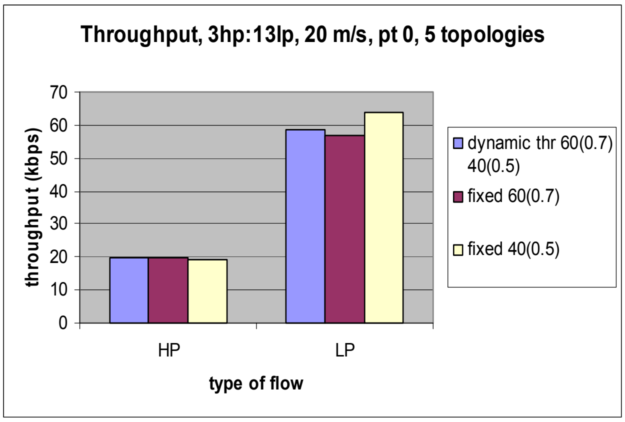

Figure 10. Throughput of high (HP) and low priority flows (LP) at 20 m/s in mobile scenario

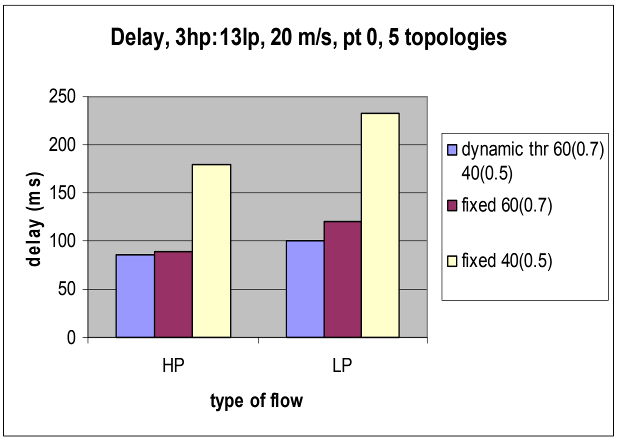

Figure 11. End-to-end delay of high (HP) and low priority flows (LP) at 20 m/s in mobile scenario

6. Conclusions

The above results shows that the dynamic p-value has a comparatively superior performance over the fixed p-value in both static and mobile scenarios in MANETs in terms of throughput to both high priority and low priority flows and significant improvement to end-to-end delay as it takes into account the level of interference between high priority flows before triggering appropriate mild or aggressive action on other flows. Our immediate experiments are to analyse the overhead of using squelch packets that are triggered when interference is detected and the performance of dynamic p-value when the number of high priority flows is increased.

7. References

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