Performance and Comparative Analysis of Design Schemes for Prioritised Data in Multi-hop Wireless Mesh Backbone Networks

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Abstract: The contention based carrier sense multiple access with collision avoidance (CSMA/CA) was originally designed for single-hop networks. For CSMA/CA to be used in multi-hop distributed networks and to provide guaranteed data priority, the CSMA/CA needs to be optimised. An application is the smart grid consisting of different network domains with data of different priority levels. The IEEE802.11e standard was developed to provide differentiated data services. With the default enhanced distributed channel access (EDCA) settings for QoS, an unfairness problem exists for different data classes where higher priority data can starve lower priority data and also where bandwidth is allocated unfairly. In this paper, we carry out an investigation of six design schemes for wireless backbone networks for QoS provisioning of different data priority classes. The design schemes are based on the concept of low-cost design for suitability in rural areas where cost plays a major role. The simulation results were obtained using OMNET++ and the INET framework. The performance metrics used for the analysis were end-to-end latency, packet loss percentage and Jain's fairness index. Simulation results show that hybrid network designs using distributed coordination function (DCF) and EDCA can improve QoS in terms of reliability and fairness.

1 INTRODUCTION

Wireless Mesh Networks (WMNs) have gained increasing popularity and use in recent years. This comes due to the characteristics of WMNs that include self organisation, auto configuration and low cost to extend network coverage. With WMNs, many challenges are also experienced such as network capacity analysis, QoS routing, link-layer resource allocation, network security, and seamless roaming (Jiang et al., 2006). Much research has been done and published in various areas of WMNs which includes routing metrics, optimum routing, security, scheduling, cross layer designs and physical layer techniques. The capacity of WMNs is affected by many factors such as network architecture, network topology, traffic patterns, network node density, number of channels used for each node, transmission power level and node mobility (Akyildiz et al., 2005).

Currently there are two main categories of MAC scheduling, namely contention based and contention free strategies. Carrier sense multiple access with collision avoidance (CSMA/CA) is a popular contention based scheme deployed in wireless local area networks (WLANs) and ad-hoc networks. The original CSMA/CA cannot perform well in wireless multi-hop environments and offers poor throughput performance and unfairness problems (Jiang et al., 2006). Although IEE802.11 and IEEE 802.11e work well in single hop networks, they present significant challenges when used in ad-hoc networks such as collision problems, throughput degradation and the collision window being increased significantly with an increase in collision and hence increasing the end-to-end delay (Yeh, 2004).

The distributed coordination function (DCF) in the IEEE 802.11 standard does not provide data priority. The IEEE 802.11e standard was developed to provide service differentiation using the enhanced distributed channel access (EDCA). For the different access categories (AC) or data classes, different arbitration interframe spacing (AIFS), different minimum and maximum contention window (CW) sizes parameters are used in the backoff procedure for service differentiation. High priority traffic gets assigned smaller AIFS and CW values compared to lower priority data classes. This gives the higher priority AC a higher chance to access the channel first compared to the lower AC. EDCA can only

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provide increased statistical chances rather than guaranteed prioritised access to higher priority traffic (Jiang et al., 2006).

For companies to setup wireless telemetry networks in rural areas such as for micro-grids or to extend the smart grid, particularly in Africa, the rate of return of their investment plays a major role as the population size is smaller and the standard of living is lower compared to urban areas with a high percentage of low income people (Sargunarangan, 2011)(Monitor, 2012). Therefore, in rural areas, WMNs may be more feasible as a more cost effective solution compared to other solutions such as fiber optic, cellular networks, WiMax or VSATs. A typical use case for WMNs viewed in this paper is the smart grid. The smart grid is comprised of many network domains that have to be interconnected to provide end-to-end services. Data in these different rural smart grid domains need to be given different priorities depending on the application domain, such as smart meter data, data from management or control domains or monitoring domains (Jeon, 2011).

We investigate six design schemes for the wireless backbone mesh networks based on the objective of determining high performance, low cost design implementations. The idea of investigating different rules assigned to edge and core routers has been taken from wired networks that provide differentiated services using Integrated Services (InterServ) and Differentiated Services (DiffServ). The edge routers perform most of the complex operations and the core routers perform simple operations. In our investigations, schemes 1, 2 and 3 are based on single radio devices using a single channel in the complete network. In schemes 4, 5 and 6, the core devices use single radios, while the edge devices use two radios with two channels. Two radios are only used in a few devices (edge devices) to keep cost of implementation low. Hardware that operate in the unlicensed Industrial, Scientific and Medical (ISM) band can also provide lower cost as compared to the use of licensed spectrum. In scheme 1, both the edge and core routers are configured with the default IEEE802.11e EDCA. In scheme 2, the edge routers are configured with the default IEEE802.11e EDCA and the core routers are configured with DCF CSMA/CA. In scheme 3, the edge routers are configured with DCF and the core routers are configured with EDCA. Scheme 4 is identical with scheme 1, scheme 5 is identical to scheme 2, and scheme 6 is identical to scheme 3 except that the edge routers use two radios and 2 channels in these designs.

The rest of this paper is organized as follows. In section 2, a brief background on the smart grid requirements is presented. In section 3, the objectives of this research are presented. Section 4 presents a brief overview of some current priority provisioning techniques. Related work is presented in section 5. Section 6 presents an overview of the proposed design schemes. Section 7 presents the simulation experimental setup details. The performance results are presented in section 8 for the proposed design schemes.

2 BACKGROUND

In developed countries, a high percentage of people are connected to the internet, while in developing countries in Africa, the case is different. A significant percentage of people in developing countries in Africa, particularly in rural areas, are living without internet. Most of the internet subscribers in developing countries in Sub-Saharan Africa are in urban areas. This leaves rural areas in Africa, particularly Sub-Saharan Africa, mostly without any internet connectivity (Johnson, 2013). This creates a digital divide. The internet bandwidth in rural areas is also very limited due to cost (Argaez 2014) (Johnson et al., 2012). The challenges faced by rural communities include the lack of communication infrastructure due to cost to provide this infrastructure (Johnson et al., 2012) (ITU, 2014).

In most cases, a rural village in Africa is up to a thousand kilometres away from urban areas and villages are also widely scattered and separated (Johnson 2013). The cost of covering this distance to reach scattered rural villages is very high. As a result, many rural deployments rely on expensive satellite links (usually VSATs or cellular networks) to provide internet access (i Direct n.d.) (Hammond and Paul, 2006).

In rural areas, lower cost and cost effective wireless communication based on WMNs may be more feasible. The settlements in these villages are usually scattered and found in clusters. The backbone network can be extended and inter-connected in a wireless mesh method to service these clusters or connect these local power generation sources. Wireless backhaul mesh networks reduce deployment cost and extend network coverage. The existence of multiple routes between source and destination nodes ensures high network availability when node or link failures occur or when channel conditions are poor (Madihian, 2007).

Table 1: Smart grid communication requirements.

Priority Category	End-to-end Latency	Applications	Reliability
HIGH	< 500ms	Emergency Response, Fault Detection, SCADA, Operations Data	99-99.9%
MEDIUM	500ms - 2s	Automated Demand Response (ADR), Direct Load Control, Transformer Monitoring, Outage Management	99-99.9%
LOW	2s - 5s	Advanced Metering Infrastructure (AMI), Real Time Pricing, Voltage and Current Monitoring, Remote connect/Disconnect	99-99.9%

For this study, the requirements of a smart grid communication network are considered. The data services have been grouped into three priority levels i.e. high, medium and low. For WMNs to be used in the smart grid, it will be expected to provide the required QoS as summarised in table 1. The network must be very reliable and provide end-to-end latency in communication within the tolerated ranges. These requirements are the same in both urban and rural networks. The advanced smart metering infrastructure can tolerate more delay than network data from fault detection networks. Detailed smart grid performance requirements in terms of latency and reliability for different smart grid applications are also stated in (Gungor, 2011) and (Jeon, 2011).

3 OBJECTIVES OF THE STUDY

Many networks carry data of different priority data, require the network to be very reliable and provide end-to-end latency within the tolerated ranges. In this paper, WMNs are investigated to provide low cost backbone connectivity for networks carrying data of different priority such as for the smart grid in rural areas as highlighted in section 2.

The objectives of this study are:

- To conduct performance measures for edge and core routers in different EDCA network design schemes to provide QoS service level differentiation.
- To improve the overall network reliability in a wireless multi-hop mesh network through hybrid network designs.
- To investigate how CSMA/CA can be configured to give optimum performance in multi-hop wireless mesh backbones.

4 PRIORITY PROVISIONING TECHNIQUES

4.1 Integrated and Differentiated Services

In wired networks, QoS provisioning is carried out using Integrated Services (InterServ) and Differentiated Services (DiffServ). The edge routers perform most of the complex operations and the core routers perform simple operations.

IntServ provides services on a per flow basis. IntServ has three main traffic classes namely, best effort service, controlled load service and guaranteed service. The best effort services are characterized by an absence of a QoS specification and the network delivers the best quality possible. In the guaranteed services classes, users are provided with an assured amount of bandwidth and end-to-end delay. In the controlled load services class, users get serviced as close as possible to the one received by a best-effort service in a lightly loaded network (Mahadevan and Sivalingam, 1999). With the IntServ, QoS support mechanisms at the network elements can be provided by various packet classifying and scheduling mechanisms such as Class Based Queuing (CBQ) and Weighted Fair Queuing (WFQ). The signalling of the flow requirements is done using the Reservation Protocol (RSVP). The RSVP protocol carries the QoS parameters from the sender to the receiver to make resource reservations along the path (Mahadevan and Sivalingam, 1999).

For DiffServ, flows are aggregated into classes and are treated according to their class, while IntServ provides per-flow guarantees. Diffserv does not need to book resources in advance as compared to IntServ. DiffServ performs mapping multiple flows into a few service levels. The 8-bit TOS (Type of Service) field in the IP header is included to support packet classification. The TOS byte is divided into 6 bit Differentiated Services Code Point (DSCP) field and a 2-bit unused field (Mahadevan and Sivalingam, 1999). The edge router operates in a wired system using DiffServ included in packet classification, packet marking and traffic conditioning. The core router functions using DiffServ include packet forwarding based on the per-hop behavior (PHB) that is associated with the packet class. DiffServ provides QoS services by differentiating between service classes. Every class gets a different Behaviour Aggregate (BA). A BA is a collection of packets with the same DSCP crossing a router node in a particular direction. Packets are forwarded according to the Per-Hop-Behaviour (PHB) associated with the DSCP (Bos, 2007). The edge routers in the network perform the complicated functions such as traffic classification and conditioning, and the core network is kept simple (without per-flow information), which makes DiffServ scalable (Jiang et al., 2006). Diffserv provide specific treatment known as per-hop treatment depending on the class of the packet.

4.2 Enhanced Distributed Channel Access (EDCA)

In wireless networks, QoS is provided using EDCA for contention based CSMA/CA. The DCF operates on a listen before talk principle known as CSMA/CA. In the DCF mode, if a node has data to transmit, it first senses the medium before transmission. If the medium is sensed to be idle for a time period known as DCF interframe space (DIFS), the station then performs a backoff procedure where a slotted backoff time is generated randomly from a contention window (CW). After this period, if the medium is found idle, transmission takes place.

If the medium is sensed to be busy, the station then waits for the channel to become idle for the DIFS period and then the backoff procedure is started again. At the first transmission attempt, the CW is set to the minimum value, CW_{min}. For any unsuccessful transmission, this value is doubled. When the contention window reaches its maximum size of 1023, it stays constant until it can be reset to CW_{min} after the successful transmission.

Many networking applications require differentiated services. This can be done by giving higher priority data preferential access to the medium. The IEEE 802.11e standard has been developed to provide differentiated services for QoS provisioning. It specifies the use of EDCA and hybrid coordination function (HCF) (Kaveh Pahlavan, 2002). EDCA is an extension of DCF and introduces the concept of access category (AC) for data types. Data is mapped at the MAC layer into the corresponding AC. The four access categories are background (BK), best-effort (BE), video (VI) and voice (VO). EDCA introduces a new interframe spacing called Arbitration IFS (AIFS). For each of the ACs, the corresponding CW values are shown in table 2.

Figure 1 illustrates the different AC's, AIFS and parallel backoff entities in EDCA in a timing diagram. AC[0] has the shortest AIFS period and back off range, compared to the lower priority data. Figure 2 shows the implementation scheduling structure of EDCA. If any queue has data, data is scheduled after sensing the medium to be idle for the AIFS period and CW backoff depending on the priority class. If data from two ACs finish the AIFS period and CW back off period, an internal collision takes place. The internal collision is handled by the virtual collision handler, where the higher priority data is allowed to transmit and the lower priority data has to contend for the medium again behaving as if a collision on the medium as occurred.

Table 2: Parameters of EDCA assigned to each AC category.

AC	AC Type	Traffic Type	AIFSN	CW_{min}	CW_{max}
AC[3]	AC_BK	Background	7	31	1023
AC[2]	AC_BE	Best Effort	3	31	1023
AC[1]	AC_VI	Video	2	15	31
AC[0]	AC_VO	Voice	2	7	15

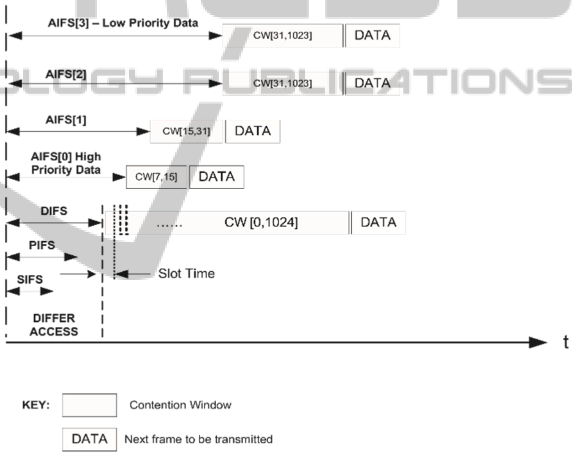

Figure 1: EDCA timing diagram.

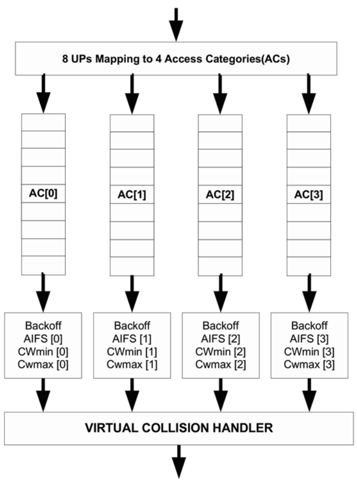

Figure 2: Reference EDCA implementation model for IEEE802.11e.

EDCA is characterised by inherent short-term unfairness (Jiang et al. 2006). One of the reasons for this unfairness is that when a node transmits successfully, it sets its CW to the CW_{min}, giving its remaining packets a better chance to be transmitted before packets from other nodes with a larger CW (Jiang et al., 2006).

5 RELATED WORK

The fairness problem in IEEE 802.11e has been mainly addressed in literature using weighted queue techniques as in (Farn and Chang, 2005), adjusting CW values as in (Kuppa and Prakash, 2004), fair queuing as in (Somani and Zhou, 2003) and (Abuzanat et al. 2009) or adaptive queuing as in (Hammouri and Daigle, 2011). Very little research has been conducted in tackling the unfairness and performance issues presented in EDCA from a design aspect.

In (Kang, 2006), a differentiated services (DS) model using IEEE 802.11e in wireless access networks is proposed. In their design, the wireless users are able to send and receive RSVP messages. The wireless access point (WAP) is configured to carry out IEEE 802.11e service differentiation, carry RSVP signals and mark packets for service differentiation in the core. This scheme was designed mainly for a hybrid model of a wired and wireless network to provide an end-to-end QoS guarantee between mobile users over the wireless access networks.

The novel contributions of this work are that we introduce a design scheme that differentiates the roles of edge and core routers. The core routers are designed to perform simple tasks such as packet forwarding based on channel contention detection, while the edge routers are designed to perform more complex tasks such as data classification and statistically scheduling data according to the priority class.

6 PROPOSED DESIGN SCHEMES

In this research, we propose and investigate six design schemes for the wireless backbone network. In the proposed schemes we assume a hierarchical backbone mesh network structure consisting of edge and core routers. User clients can connect to the edge routers, while the core routers connect to the backbone routers and carry the data in the backbone. Figure 3 shows the six design concepts used in our investigation.

The schemes are based on the concept of low cost design implementation solutions and hence we investigate designs 1, 2 and 3 for single radio and single channel for both edge and core devices. Schemes 4, 5 and 6 are the same designs as schemes 1, 2 and 3, with the addition of an additional radio in the edge nodes and an additional channel. In schemes 1, 2 and 3, omni-directional antennas are used. In schemes 4, 5 and 6, omni-directional antennas are used, with 1 radio in the edge devices connecting the user devices and the other antenna connecting the backbone devices. Non-overlapping channels are used.

In schemes 1 and 4, EDCA is configured in both the edge and core routers. In schemes 2 and 5, DCF is configured in the core routers and EDCA is configured in the edge routers. In schemes 3 and 6, EDCA is configured in the core routers and DCF is configured in the edge routers.

7 SIMULATION ENVIRONMENT

To investigate our design concepts, simulations were set up in OMNET++ using the INET framework. OMNET++ is an open source application. The INET framework offers detailed modelling of radio propagation, interference estimation, implementation of various MAC, network layer, and transport and application layer protocols of wireless network (Ganlenbein, 2010). Table 3 gives details of the simulation setup implemented in OMNET++ using the INET framework. In our designs, we assume no capture effects, and no hidden terminal or exposed terminal problems. Simulations were carried out on different network sizes. The maximum network size for the backbone mesh used in the simulations was 36, as in real life deployments a network using this many nodes can cover a comparatively large area in outdoor applications. The standard IEEE802.11e model with AC[0] for high priority data, AC[1] for medium priority data and AC[2] for low priority data was used. The traffic type was heterogeneous with different priority levels.

For each of the 6 design schemes, 3 experiments were carried out on different network topology sizes (3x3, 4x4 and 5x5). Therefore, a total of 18 experiments were carried to obtain the results for the performance analysis. The experiments were each repeated twice to verify the results. The confidence interval was 95%.

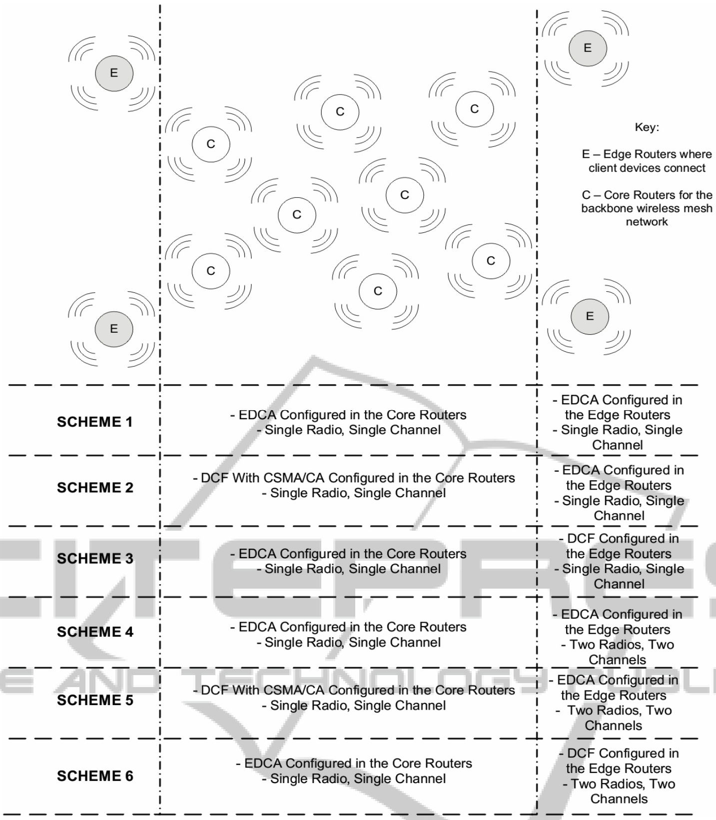

Figure 3: Proposed design schemes for the wireless backbone mesh network.

Table 3: Simulation Environment.

Network Setup	
Simulation Time	300 seconds
Topologies type:	Grid Topology
Number of Nodes	16, 25 and 36 for the backbone
Mesh Sizes for Backbone nodes	4x4, 5x5, 6x6
Backbone separation Distance	300m between nodes
Area	2.2km x 2.2km = 4.84km^2
Propagation Model	Free Space Model
Carrier Frequency	2.4GHz
Data rate	54Mbits/s
Application Data	UDP Basic Burst Packets
Data Categories	3 categories of Data - Low, Medium and High Priority
Packet Size	512bytes
Rate of Transmission	100 packets/second

User Data Protocol (UDP) data was used in our simulations for the three types of priority data. UDP does not establish connections between the source and destinations (connectionless) and also there are no retransmission of lost packets (Xylomenos and Polyzos, 1999). The use of UDP packets help determine the reliability of the network through packet loss measures. On the other hand, Transmission Control Protocol (TCP) is connection oriented and also feedback is received for delivered packets (Xylomenos and Polyzos, 1999).

To test the possibility of nodes dropping packets and also higher priority data starving lower priority data, the arrival data rate for all the data classes was set to 100 packets/sec. In many real life situations, the end devices are usually randomly distributed which gain access to the network by connecting to the backbone devices. In rural settings in Africa, it is possible to layout backbone grid topologies or topologies that are close to grid topology due to large open areas as mentioned briefly in section 2. Grid topologies provide a high number of mesh links and hence increase the reliability when some node connections are lost.

To assess the performance of our proposed design schemes and carry out the comparative analysis, end-to-end latency, packet loss (%) and Jain's Fairness Index metrics were used:

1. End-to-end latency: This is the average time taken by a data packet to arrive at the destination from the source. It includes all the delay experienced from the source to the destination which includes route discovery processes, data queuing and packet transmission. Only the data packets successfully delivered to the destinations are used in these calculations (Vardakas et al., 2007).

2. Packet Loss: This is the measure of the percentage of packets lost from the source to the destination. This value was measured at the destination as (Periyasamy, 2014):

$$\text{Packet Loss (\%)} = \frac{(N_t - N_r)*100}{N_t} \quad (1)$$

Where N_t is the number of packets is transmitted and N_r is the number of packets received.

3. Jain Fairness Index (JFI): A fairness index is a measure of how fair or unfair the resources are shared among the competing hosts. Equation 2 is used to calculate fairness where x_i is the normalized throughput of station i, and n is the number of flows in the WMN. A JFI of 1 indicates absolute fairness and a JFI of 0 absolute unfair resource distribution (Deng and Han, 2009). In our case n=3 as we investigate the fairness for 3 data classes namely for high, medium and low priority classes.

$$f(x_0, x_1, x_2, \ldots, x_n) = \frac{\left(\sum_{i=0}^{n} x_i\right)^2}{n\left(\sum_{i=0}^{n} x_i\right)^2} \quad (2)$$

$$where\ 0 \leq f(x_0, x_1, x_2, \ldots, x_n) \leq 1$$

8 RESULTS

The performance of the six schemes were analysed in terms of packet loss in figures 4 to 9. Figure 4 displays the packet loss for high priority data in schemes 1, 2 and 3. Scheme 2 experienced the least packet loss for high priority data in a 4 by 4 network and 5 by 5 network. Scheme 3 experienced the least packet loss in a 6 by 6 network for high priority data. For high priority data in schemes 4, 5 and 6 as can be seen in figure 5, scheme 5 experienced the least packet loss. Figure 6 displays the packet loss for medium priority data in schemes 1, 2 and 3. Scheme 2 experienced the least packet loss for medium priority data in all investigated topology sizes. For medium priority data in schemes 4, 5 and 6 as can be seen in figure 7, scheme 5 experienced the least packet loss. Figure 8 displays the packet loss for low priority data in schemes 1, 2 and 3. Scheme 2 experienced the least packet loss for low priority data in 4 by 4 and 5 by 5 topologies. Scheme 1 experienced the least packet loss in the 6 by 6 topology. For low priority data in schemes 4, 5 and 6 as can be seen in figure 9, scheme 5 experienced the least packet loss. Overall, in the single radio and single channel schemes (schemes 1, 2 and 3), scheme 2 which uses DCF in the core routers and EDCA in the edge routers performed the best. In the two radio and two channel schemes (schemes 4, 5 and 5), scheme 5 which uses DCF in the core routers and EDCA in the edge routers performed the best in terms of least packet loss. For both schemes 2 and 5, DCF is configured in the core routers and EDCA in the edge routers. DCF is the core routers gives all packets carried in the core network an equal chance of medium access and also packets are transmitted in a first in first out (FIFO) fashion in the core network. Doing this reduces the collision probability for high and medium priority data. The performance in terms of packet loss reduction improves with the addition of the additional resources in the edge nodes as in scheme 5. Edge routers in real life networks are usually subjected to more traffic load and congestion. The multi-radio and multi-channel scheme used in scheme 5 helps lower the packet loss considerably. Packet loss reduces in the hybrid design of DCF in the core routers and EDCA in the edge routers as the number of collisions is expected to have reduced due to a larger CW range in the core routers. DCF have larger CW ranges and contention periods compared to the differentiated IEEE802.11e services differentiation scheme. Higher range values of CW with larger back off intervals reduce the collision probability.

Figures 10 to 16 present the end-to-end latency experienced for the six design schemes. Figure 10 shows the end-to-end latency for high priority data in schemes 1, 2 and 3. It can be seen that high priority data in scheme 1 experienced the least end-to-end latency compared to schemes 2 and 3. Figure 11 shows the end-to-end latency for schemes 4, 5 and 6 for high priority data. Schemes 5 and 6 high priority data experienced more latency compare to scheme 4. The single channel, single radio schemes (1, 2 and 3) experience more delay then the 2 channel and 2 radios in the edge devices (schemes 4, 5 and 6). Figure 12 shows the end-to-end latency in schemes 1, 2 and 3 for medium priority data. Schemes 2 and 3 medium priority data experienced a considerable increase in latency compared to scheme 1. In figure 13 for medium priority data for schemes 4, 5 and 6, an increase in latency can be observed for schemes 5 and 6 compared to scheme 4. In figure 14 for low priority data for schemes 1, 2 and 3, schemes 2 and 3 also experience an increase in latency compared to scheme 1. The increase in latency for schemes 2 and 3 for low priority data is not as much as that experienced for high and medium priority data. With the hybrid design schemes with the DCF, each priority data class are given a fixed DIFS and CW backoff interval which results in an increase in end-to-end latency for high and medium priority data. It can be observed that for the cases of EDCA configured in both edge and core routers, the latency experienced was the least. For the schemes where DCF was configured in the core routers and EDCA was configured in the edge routers, a higher end-to-end latency was experienced then the scheme with all EDCA configured routers. The scheme where DCF was configured in the core routers and EDCA was configured in the edge routers, also experienced higher end-to-end latency compared to the scheme where EDCA was configured in the core routers and DCF in the edge routers.

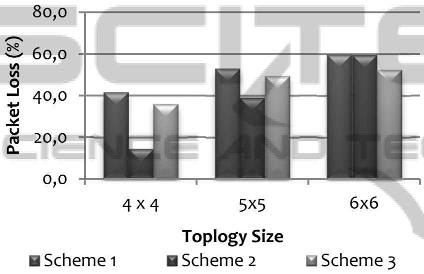

Figure 4: Packet loss for high priority data for schemes 1, 2 and 3.

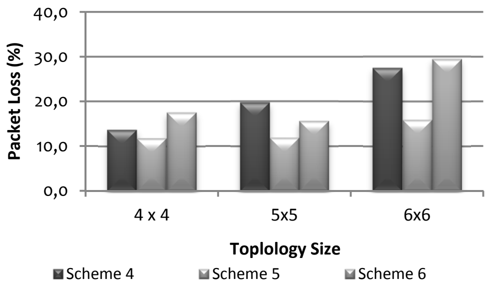

Figure 5: Packet loss for high priority data for schemes 4, 5 and 6.

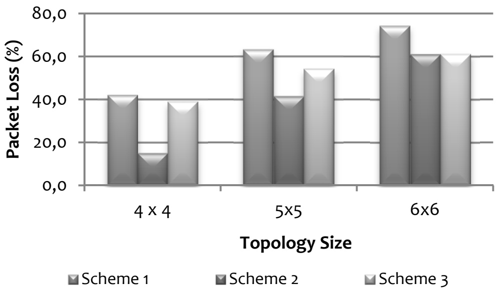

Figure 6: Packet loss for medium priority data for schemes 1, 2 and 3.

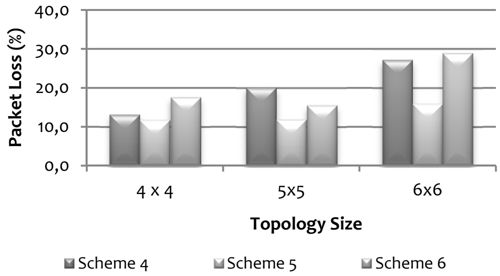

Figure 7: Packet loss for medium priority data for schemes 4, 5 and 6.

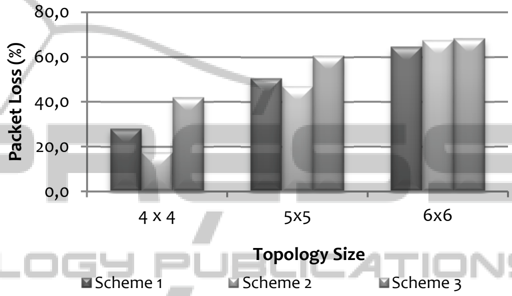

Figure 8: Packet loss for low priority data for schemes 1, 2 and 3.

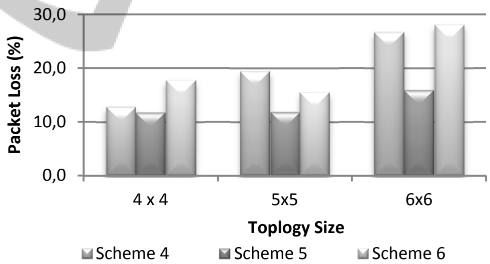

Figure 9: Packet loss for low priority data for schemes 4, 5 and 6.

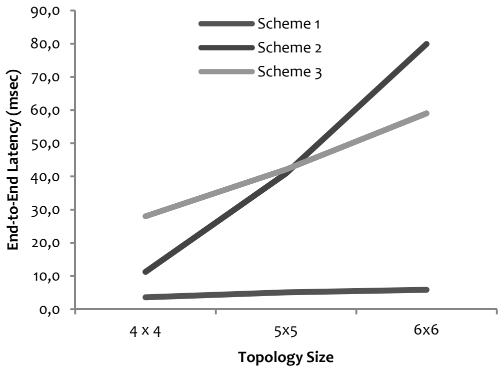

Figure 10: End-to-end latency measured for high priority data in schemes 1, 2 and 3.

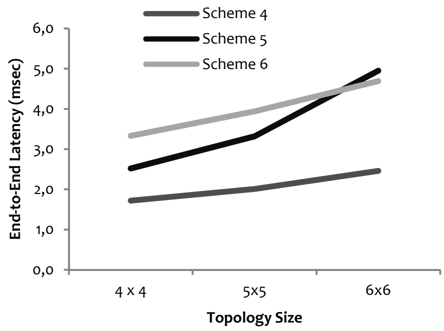

Figure 11: End-to-end latency measured for high priority data in schemes 4, 5 and 6.

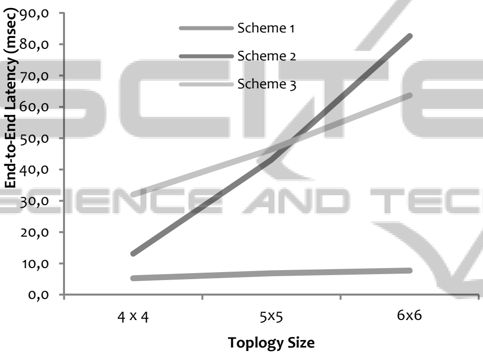

Figure 12: End-to-end latency measured for medium priority data in schemes 1, 2 and 3.

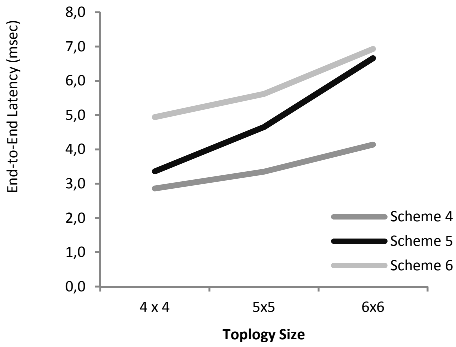

Figure 13: End-to-end latency measured for medium priority data in schemes 4, 5 and 6.

With the default EDCA, an unfairness problem exists as mentioned where higher priority data can starve lower priority data. The Jain's fairness index for all the six schemes is shown in figure 16. For the single radio and single channel schemes (schemes 1, 2 and 3), scheme 2 provided the highest fairness.

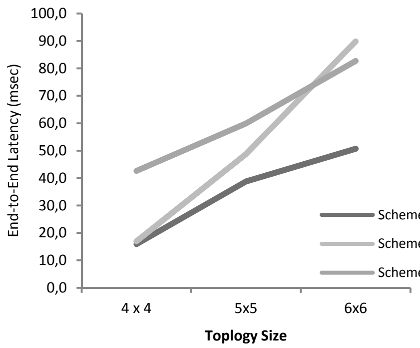

Figure 14: End-to-end latency measured for low priority data in schemes 1, 2 and 3.

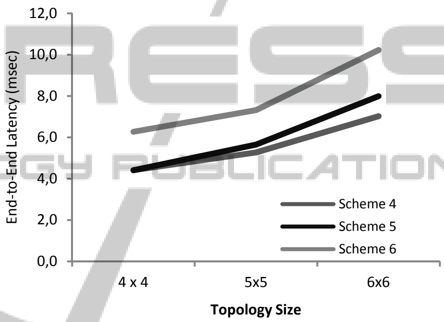

Figure 15: End-to-end latency measured for low priority data in schemes 4, 5 and 6.

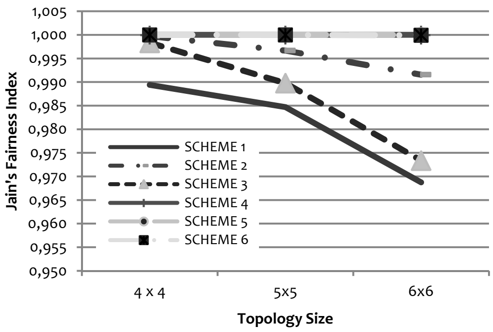

Figure 16: Fairness indication of the three schemes using Jain's Fairness Index.

The two radios, two channels schemes configured in the edge routers, all provided fairness of 1. The network design in scheme 2 is shown to provide higher fairness. Schemes 2 and 5 give an equal chance probability to all data priority classes in the core network which improves fairness in the network.

9 CONCLUSIONS

In this paper the use of CSMA/CA in multi-hop distributed backhaul networks to provide guaranteed data priority under different design schemes was investigated. We investigated the performance of six design schemes for wireless backbone mesh networks. Different roles were assigned to the edge and core routers. Schemes 1, 2 and 3 used single radio and single channel in core and edge routers. In Scheme 1, all routers performed the same role and were configured with EDCA. In Scheme 2, the edge routers performed data classification and were configured with EDCA. The core routers in Scheme 2 were only configured with the default DCF. In scheme 3, DCF was configured in the edge routers and EDCA in the core routers. Schemes 4, 5, and 6 were identical to schemes 1, 2 and 3 with the addition of another radio in the edge routers and an additional channel in the network.

The hybrid design scheme where DCF was configured in the core routers and EDCA in the edge routers experienced the least packet loss. This was due to a reduction in the number of collisions as DCF have larger CW ranges and contention periods compared to the differentiated IEEE802.11e services differentiation scheme. Higher range values of CW with larger backoff intervals reduce the collision probability. The different data packets carried in the backbone devices with DCF configured have an equal chance of gaining access to the medium and the scheduling of packets operate as a FIFO scheduling in the backbone devices.

The scheme with all routers configured with EDCA in both edge and core routers, experienced the least latency. This is as a result of the service differentiation with higher priority data waiting less time to access the medium. The schemes where DCF was configured in the core routers and EDCA was configured in the edge routers, experienced higher delay then the EDCA scheme with all EDCA routers. For the single radio and single channel schemes (schemes 1, 2 and 3), scheme 2 provided the highest fairness.

Networks that require high reliability, but can tolerate more end-to-end latency, a hybrid design scheme, where DCF is configured in the core routers and EDCA is configured in edge routers will be a good design to use. Rural smart grid networks can be a potential application for this design scheme.

The fairness problem in IEEE802.11e in literature has been mainly addressed using weighted queues, adjusting CW values adaptively and differentiated services models among others. The novelty of this work was the improvement of fairness from a design aspect by assigning different roles to edge and core devices.

The objectives of the paper have been met where DCF configured in the core routers and EDCA configured in the edge nodes provides a hybrid design scheme that is more reliable with less packet loss compared to a design with EDCA configured in all nodes. This hybrid design scheme also provides more fairness for data of different priority. Hybrid design schemes reduce collisions and hence result in improved throughput.

Edge routers are subjected to more traffic load and congestion in networks. The multi-radio and channel scheme at the edge routers helps prevent congestion. Further work would entail developing fair scheduling schemes.

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