Protection Schemes for 4G Multihop wireless Networks

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Abstract:-This paper describes the relay node protection using network coding for fourth generation multihop wireless networks and analises the QoS performance with the proposed scheme. The Quality of Service performance, such as PDR, latency and jitter, are measured for different scenarios. The scenarios for 4G wireless networks include failure of a single and two relay nodes, with and without the protection scheme, and user's mobility.

Keywords: *Multihop, Protection, Packet Delivery Ratio, QoS, WiMax, LTE etc…*

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1. Introduction

In general, node protection in a communication network guarantees the traffic flow from source to destination. Traditional protection schemes in wired networks introduce either resource-hungry solutions, such as the (1+1) protection scheme, or a delay and interrupt to the network operation as in the (1: N) protection scheme. Node protection using network coding could solve the above issues. However, the existing research efforts are concentrated on wired networks, and not much research has been conducted on wireless multihop or mesh networks. The data transmission using Relay Stations extends the coverage region and capacity in fourth generation multihop wireless networks.

In traditional (1:1) node protection, transmissions on the backup path only take place in case of a failure and in the (1+1) protection the traffic is simultaneously transmitted on two link disjoint paths. Implementing the traditional (1+1) protection scheme increases the capital cost, and resources cannot be fully utilized. The design and implementation of the (1: N) protection scheme in wireless networks is more challenging for the system design and is difficult as well. On the other hand, the network coding is introduced in wireless networks for traffic redundancy for the replacement of Hybrid Automatic Repeat request (HARQ) techniques. Now, the network coding is extended for the protection of wireless relay nodes. In multihop wireless networks, very few research efforts are concentrated on node protection schemes using network coding.

2. Relay Node Protection Using Network Coding

Network coding has recently been introduced as a new transmission paradigm in wireless networks. Initially network coding was introduced for wired networks. Even though network coding is ideally suited for wired networks, it has some limitations in traditional wireless cellular networks due to the centralized network architecture and the occurrence of interference in the transmission of network coded data. Therefore, the extension of network coding to wireless networks is not straightforward. However, the existing research efforts show that the network coding is well suited in 4G wireless networks for a few different applications. Those applications are mainly focused on data reliability.

Initially, WiMAX and LTE standards use HARQ to transmit the data packets reliably. However, HARQ may under utilize the wireless medium in the cases of multipath and multihop transmissions. Hence, network coding is tested for various scenarios such as single-hop, handover and multihop, where network coding outperforms HARQ. Later, network coding is studied for various applications such as video traffic, multicast, etc., for reliable transmission in WiMAX and LTE networks. Similarly, the recent research efforts are concentrating on node protection using network coding on WSN and WMN. However, the QoS performance of network coding for node protection has not been tested until now. Therefore, the QoS performance of node protection using network coding is studied for WMNs and then extended for multihop WiMAX networks. For multihop LTE networks, similar performance could be achieved.

The multihop WiMAX/LTE network architecture is shown in Figure 1 (for simplicity, only two-hops are considered). The network elements in WiMAX networks include the BS, RS and MS, whereas the network elements in LTE consist of eNB, Relay Node and UE. The relays, RS1 and RS2, are used to extend the coverage region of the network. Hence, the cell edge mobile users are connected to the network through the relay RS1 or RS2. For the WMN, the BS in Figure 1 is replaced by the gateway node, the RS is replaced by a relay (r) and MS is replaced by the user's source node (S).

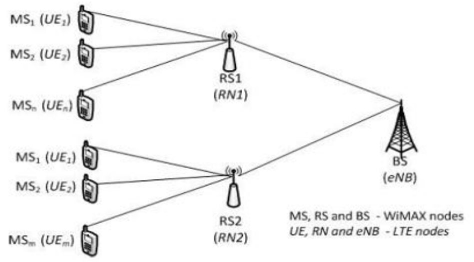

Figure1: Multihop relay network architecture – WiMAX/LTE

To enable the protection for wireless relay nodes XOR network coding can be used, where XOR is simple to understand and for concept validation.

3. Protection for Single Relay Node Failure

For protection against single relay node failure for the network topology as shown in Figure1, an extra RS is added to the network and all relay nodes should use network coding. This design emulates the 1:N relay node protection scheme for wireless networks.

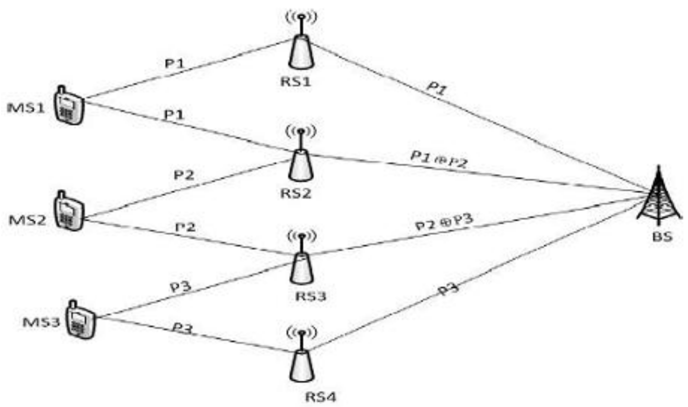

Figure 2: Network model - Protection for single relay node failure

The network topology considered for protection of a single RS failure is shown in Figure 2. The network consists of three cell edge users, namely MS1, MS2 and MS3, one BS (eNB for LTE) and four forwarding relays, RS1, RS2, RS3 and RS4. For instance, without protection, the network requires, at most, three RSs, each connecting to a MS. With the protection, four RSs are used. Each relay node is capable of encoding the packets from different sources using the XOR network coding scheme. The receiver node, BS, is capable of decoding the XOR coded packets from different relays. However, to adapt to the protection in WiMAX networks, the network should use soft handover for the operations, because the MS needs to communicate with more than one BS/RS at the same time. From the statement for relay node protection, the receiver node BS can retrieve the information for a single relay failure if, and only if, the source node has a minimum of two edge-disjoint paths, e.g. m = 2. Since each source node is connected to two relays, they have two edge-disjoint paths to the BS. Relays RS1 and RS4 forward only the regular packets P1 and P3, respectively; but relays RS2 and RS3 forward network coded packets of P1⊕P2 and P2⊕P3, respectively. For the network topology illustrated in Figure 2, if RS1 fails, the BS first obtains P3 from RS4, and then the BS decodes P2 and P1 from RS3 and RS2, respectively. In other words, P2 and P1 are decoded from the coded packets P2⊕P3 and P1⊕P2. Similarly, the BS can retrieve the information for other single RS failure.

4. Protection for Two (multiple) Relay Nodes Failure

The network architecture for two relay failures scenario is shown in Figure 3. In this scenario, each MS has to maintain a set of three RSs in a diversity set. The diversity set maintained by MS1 is RS1, RS2 and RS3; MS2 is RS2, RS3 and RS4; and MS3 is RS3, RS4 and RS5, respectively. Now, each source node has a minimum of three disjoint paths (i.e., m = 3) to the receiver BS. The relays RS1 and RS5 forward the original packets, P1 and P3, respectively. The remaining relays, RS2, RS3, and RS4, forward the network coded packets of P1⊕P2, P1⊕P2⊕P3 and P2⊕P3, respectively.

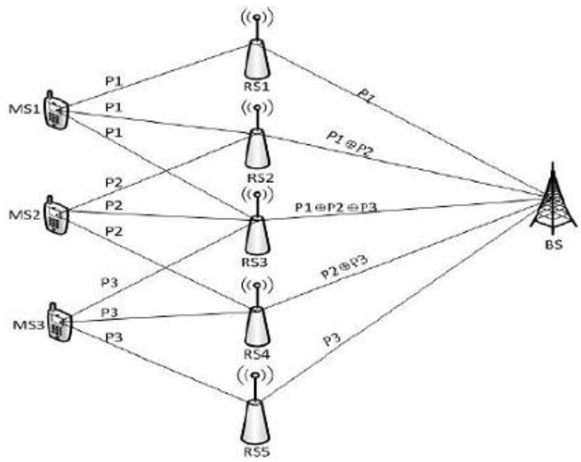

Figure 3: Network model - Protection for two relay node failures

Assume that two relays RS1 and RS2 failed as presented in Figure3.The BS can still decode all the packets for P1, P2, and P3. The BS first obtains P3 from RS5, and then decodes P2 and P1 from RS4 and RS3, i.e., the BS decodes P2 from P2⊕P3 and finally, P1 from P1⊕P2⊕P3, respectively. Similarly, the receiver can decode all P1, P2 and P3 if, at most, two of the any relays RS1, RS2, RS3, RS4 and RS5 fail.

5. Performance Evaluation of Relay Node Protection using Network Coding

The proposed relay node protection is tested only for the WiMAX network. However, similar performance could be achieved for LTE networks. The network considered for single and two RSs protection is shown in Figure 2 and Figure 3. The simulation tool used for WMNs simulation is NS2.28, and the network considered for protection against single and two relay node failures is similar to Figure 2 and Figure 3. For the WMNs simulation, first the network coding protocol is integrated into the IEEE 80.11b protocol in NS2. The other simulation parameters considered for this simulation are given in Table1. Similarly for the WiMAX network, both network coding and WiMAX patches are integrated to NS2.28. The WiMAX and other system parameters considered for this simulation are given in Table 2.

Table 1: System Parameters for Wireless Mesh Networks Simulation

Parameters	Value
Radio-propagation model	Two way Ground
MAC Protocol	IEEE 802.11b
Network Coding type	XOR
Routing	Broadcast(CODEBCAST)
Link Capacity	54Mbps
Packet Size	1000bytes
Data Rate(in Kbps)	64,128,256,512 and 1024

Table 2: System Parameters for WiMAX Networks Simulation

Parameters	Value
MAC Protocol, NS2 Patch	Multihop WiMAX, NIST
Physical Layer	Wireless MAN OFDMA,TDD
System Bandwidth	20MHz
Frame Duration	5msec
Radio-propogation model	Cost-231
Network coding type	XOR
Routing	Broadcast(CODEBCAST)
Packet Size	1000 bytes(Fixed for all data rates)
Data Rate(in Kbps)	64,128,256,512 and 1024
Mobility Model	Random way Point

The QoS performance is analyzed for single and two relay nodes failure scenarios as presented in Figure 2 and Figure 3 (except Case 5 and Case 8 in the below list). However, the user's mobility is not considered for the WMNs. For WiMAX network, a single RS failure scenario considers only the relay RS1 failure in Figure 2, because the QoS performance is the same for other RSs (RS2, RS3 and RS4) failure as in the case of WMNs. Similarly, two RS failures scenario considers only the failure of RS1 and RS2 as presented in Figure 3. Hence, the final scenarios considered for WiMAX networks simulation include:

- **Case 1**: static user, no RS failure and no protection: For the network as shown in Figure 2, relays RS1, RS2 and RS3 forward regular packets from users MS1, MS2 and MS3 to the BS. The relay R4 is not considered. All user nodes are static and there is no RS failure in a network.
- **Case 2**: static user, one RS failure and no protection: In this scenario, relays RS2 and RS3 forward regular packets from users MS2 and MS3 to the BS. The relay RS4 is not considered and RS1 fails to forward the packets (P1) as presented in Figure 2.
- **Case 3**: mobile user, no RS failure and protection enabled: As the protection scheme is enabled, relays RS2 and RS3 forward network coding packets as shown in Figure 2. The user MS1 moves away from the RS1 but within RS2 and RS3 network coverage, that is, the diversity set of MS1 is RS2 and RS3. The user movement in other directions is not considered to show the limitation of XOR network coding.
- **Case 4**: static user, one RS failure and protection enabled: For the given network scenario as presented in Figure 2, RS1 fails to forward packets. The relays, RS2 and RS3, forward network coding packets and RS4 forwards regular packets.
- **Case 5**: mobile user, one RS failure and protection enabled: For the given network scenario as presented in Figure 2, RS1 fails to forward packets. The relays, RS2 and RS3, forward network coding packets and RS4 forwards regular packets. The user MS1 moves away from the RS1 but within RS2 and RS3 network coverage (diversity set of MS1 is RS2 and RS3).
- **Case 6**: static user, two RS failure and no protection: In this scenario, the relay RS3 forwards regular packets from the user MS3 to the BS. The relays RS4 and RS5 are not considered, and relays RS1 and RS2 fail to forward packets as presented in Figure 3.
- **Case 7**: static user, two RS failures and protection enabled: For the given network scenario as shown in Figure 3, the relays, R1 and R2, fail to forward packets. Other relays, RS3 to RS5, are working properly, whereas RS3, RS4 forward encoded packets and RS5 forwards regular packets. All MSs are static in a network.
- **Case 8**: mobile users, two RS failures and protection enabled: In this scenario, the relays, RS1 and RS2, fail to forward packets in a network as shown in Figure 3. Other relays, RS3 to RS5, are working properly, whereas RS3, RS4 forward network coding packets and RS5 forwards a regular packet. The MSs, MS1 and MS2 are moving away from the network coverage of RS1 and RS2. Their new diversity sets are RS3, RS4 and RS5 for MS1; RS4 and RS5 for MS2.

PDR performance: PDR is the ratio of the total number of packets received at the receiver node over the total number of packets transmitted at all sender nodes.

$$PDR = \frac{\text{Total number of packets received at R}}{\text{Total number of packets transmitted at (S1+S2+S3)}}$$

Figure 4 shows the PDR results for the first four scenarios with, at most, one failure in WMNs. The fifth scenario considered in this simulation is r2/r3 relay node failure, where the relay node fails to forward the network coded packet. From the graphs, it is clear that PDR for case 1 (no protection and no failure) and case 3 to case 5 (protection with, at most, one failure) are pretty much the same and the graphs overlap. When the data rate is low (64Kbps), the PDR is approximately 99%, and it reduces for high data rate (≈90% for 1024Kbps). However, the PDR performance for case-2 (no protection and r1 failure) is only about 66% of other schemes. In case 2, the gateway receives data from S2 and S3 only, the relay node r1 fails to forward the packet P1, from S1. In case 4 and case 5, even though one relay node fails, the gateway can retrieve all the senders' information.

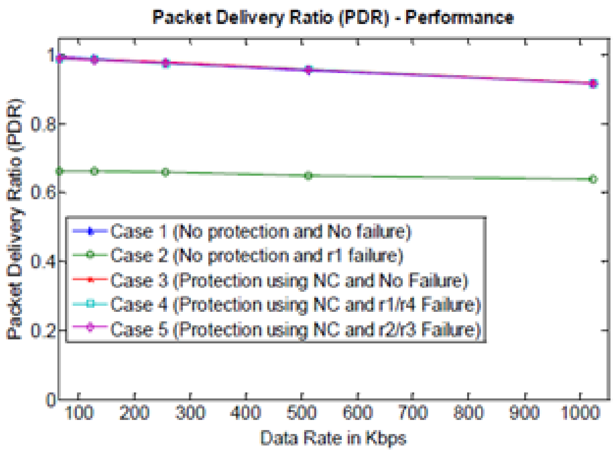

Figure 4: PDR for single relay node protection scenarios in WMN

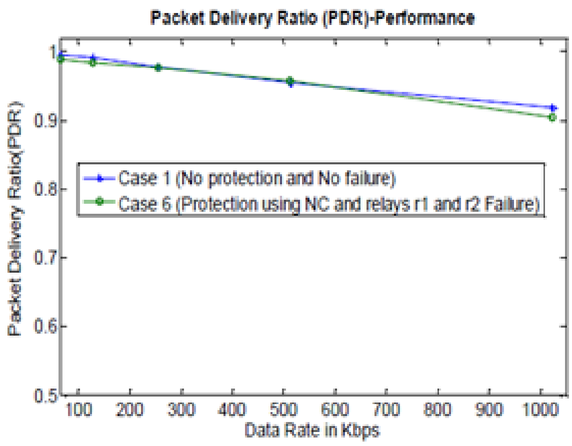

Figure 5: PDR for two relay nodes protection scenarios in WMN

Figure 5 shows the PDR performance for case 1 (no protection and no failure) and case 6 (protection against two relay nodes failure and relays r1 and r2 failure) scenarios in WMNs. From the graph, it is clear that the protection scheme works well for two relay nodes failure as well, and the PDR performance is close to the no protection and no failure scenario..

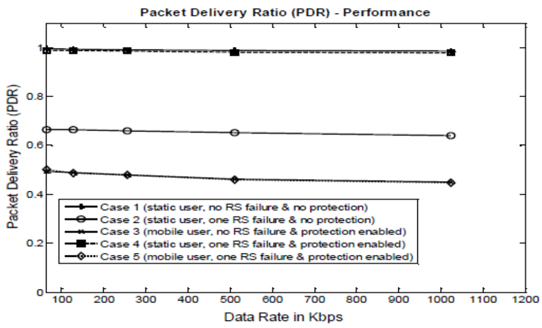

Figure 6: PDR for single RS protection scenarios in WiMAX network

Figure 6 shows the PDR performance for the first five scenarios with at most one RS failure in WiMAX networks. It can be seen that the PDR results for case 1 (static user, no failure and no protection), and case 4 (static user with, at most, one RS failure and protection enabled) are close, as the curves are overlapping. In case 4, even though the RS fails, the BS is able to decode the MS1 packets from network encoded packets.

Limitation in XOR network coding: From the PDR performance results in WiMAX networks, it is shown that the PDR for mobility scenarios, such as case 3 and case 5, are very low due to a decoding problem at the receiver node (BS). In mobility scenarios, both RS2 and RS3 forward the network coding packets of P1⊕P2 and P1⊕P2⊕P3 and then RS4 forwards the regular packet P3. Therefore, the BS is able to decode P3 only and then BS has two copies of P1⊕P2.

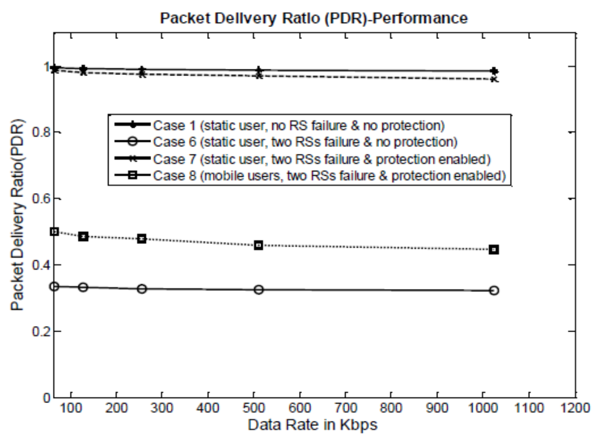

Figure 7: PDR for two RSs protection scenarios in WiMAX Scenarios in WMN

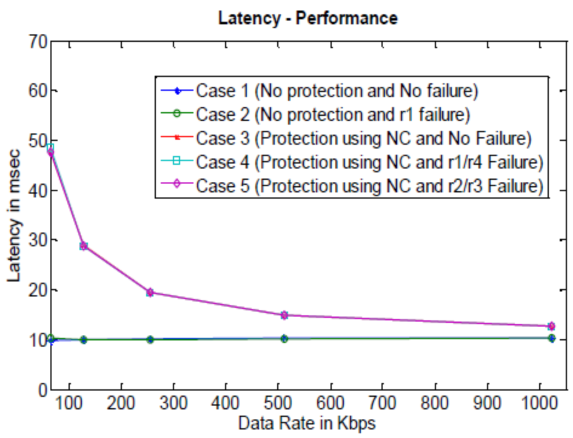

Figure 8: Latency for single relay node protection

Figure 7 shows the PDR performance of no RS failure and two RSs failure cases including user's mobility. The PDR for case 1 (static user, no failure and no protection) and case 7 (static user, two RSs failure and protection enabled) are similar, and the graphs are overlapped. From the graph, it is clear that the protection scheme works well for two RSs failures.

Latency performance: The average latency is calculated by dividing the total delay of an individual transmitted packet by total transmitted packets. Further, the latency is calculated only for the successfully received packets. Figure 8 shows the latency results of no protection (case 1 and case 2) and protection against single relay node (case 3 – case 5) schemes in WMNs.

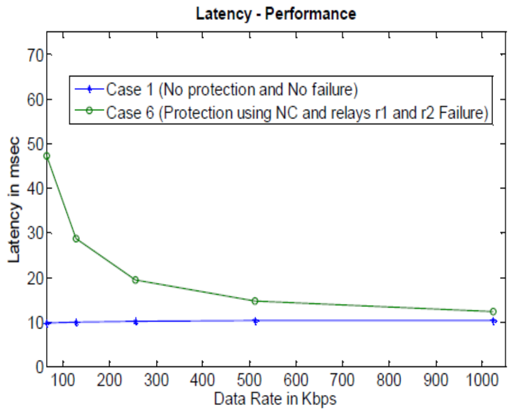

Figure 9: Latency for two relay nodes protection scenarios in WMN

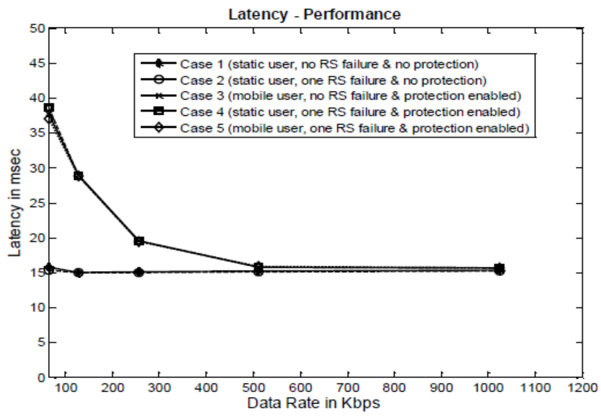

Figure 10: Latency for one RS protection scenarios in WiMAX network

Figure 9 shows the latency results of case 1 and case 6 scenarios. The latency of protection against two relay node failure scheme is similar to the protection against single relay failure schemes as illustrated in Figure 8. Apart from the transmission delay, the major factor affecting the latency performance is the inter-arrival time of the packet from different service flow at the RS. When the inter-arrival time of different service flow is high at the RS, to receive the entire encoded packet at the BS takes long time that increases the decoding delay. Figure 10 shows the latency results for no protection scenarios and protection against single RS failure scenarios in WiMAX networks.

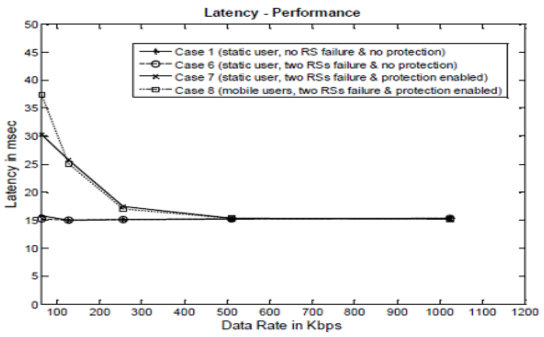

Figure 11: Latency for two RSs protection scenarios in WiMAX network

Figure 11 shows the latency results of no protection and protection against two RSs scenarios. The latency is approximately 15msec for no protection scheme. Latency s.

for protection enabled schemes is approximately 35msec for low data rate and merges to no protection scheme at higher data rate. Jitter is calculated by measuring the delay difference between ith transmitted packet and (i-1)th packet. Figure 12 and Figure 13 demonstrate the results for jitter. From Figure 12, it is clear that jitter for no protection schemes (case 1 and case 2) and protection against single relay node schemes are almost the same (0.3msec), except for the case 4 scenario (protection against single relay node failure and r2/r3 failure) at low data rates. In case 4, when a regular data forwarding relay node fails (r1 or r4 as presented in Figure 2), the gateway has to wait for P3 from r4, P2 can then be decoded through P3 and P2⊕P3, and, finally, P1 can be decoded through P2 and P1⊕P2. This leads to an increase in latency and jitter for low data rate

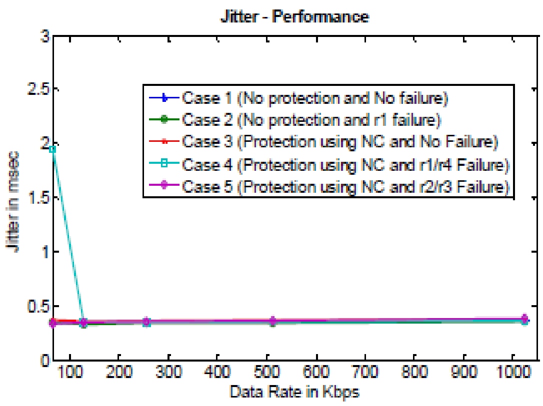

Figure 12: Jitter for single relay node protection scenarios in WMN

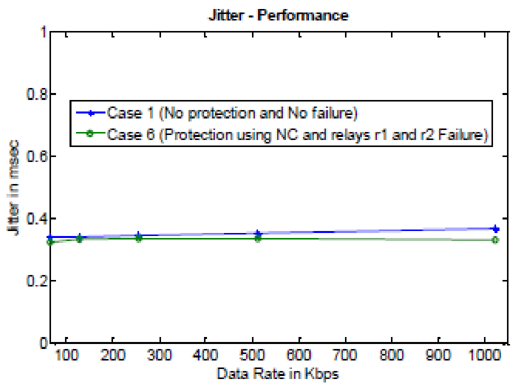

Figure 13: Jitter for two relay nodes protection scenarios

Figure 13 shows the jitter performance for case 1 (no protection and no failure) and case 6 (protection against two relays failure and the relays r1 and r2 fail as presented in Figure 3). Both cases have similar jitter results.

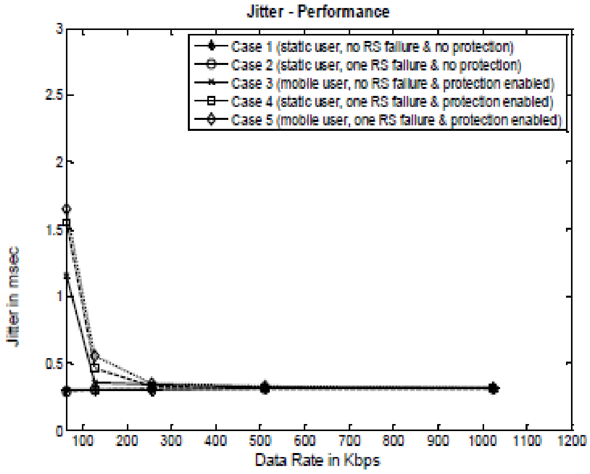

Figure 14: Jitter for single relay node protection scenarios WiMAX

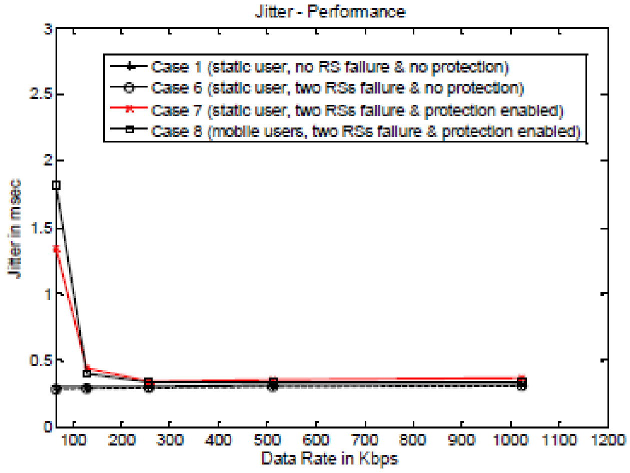

Figure 15: Jitter for single relay node protection scenarios in

The jitter performance for single and two relay nodes failure scenarios are shown in Figures 14 and Figure 15. The jitter performance for case 1 and case 2 in Figure 14 for no protection schemes is almost the same. The jitter performance on protection for two RSs in Figure 15 is similar to protection against single RS failure scenarios as presented in Figure 14.

Conclusion

In this paper, the protection scheme against failure of relay nodes was introduced for WMNs and 4G wireless networks to increase reliability. The QoS performance PDR, latency and jitter were measured to study the reliability, that is, the impact of the protection scheme. For a single relay node protection, the addition of one more relay node and the implementation of network coding are needed on the existing network architecture. As a result, this design simulates the 1:N relay node protection scheme for wireless networks. Similarly, protection against the two relay nodes failure scenario requires two additional relay nodes.

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