A Collaborative Routing for Wireless Multi-hop Networks with Directional Antennas

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Abstract— **In this paper we propose a collaborative routing protocol (CORP) for wireless multi-hop network with directional antennas that utilizes the wireless broadcast advantage (WBA) properties. In CORP, the neighboring nodes collaborate with each other to directionally forward the packets when an intermediate relay node is unable to perform its task due to channel/node failure. The process of collaboration is supported by the RSS value obtained from the MAC layer to form the set of collaborating nodes. The temporary link formed by the collaborating node will maintain the ongoing transmission until the old route is recovered or a fresh route is generated. We performed simulation studies using QualNet to prove that our protocol is suitable for wireless multi-hop networks that are prone to frequent node/link failure.**

Keywords- Collaborative routing, Wireless Multi-hop Networks, Directional Communication.

I. INTRODUCTION

Wireless technologies are capable of solving various problems that the wired infrastructures face today. For example, the reduction in installation and management costs, convenience in management, and wider coverage and extensions make wireless a much more admirable technology in the ubiquitous world. However, wireless community still faces many problems that must be solved for full utilization, such as medium sharing, interference, resource management, etc. Especially, communication interference that can occur between several simultaneous transmissions or from environmental factors is one of the major problems that need to be solved.

To reduce the interference in a network, the concept of directional communication has been proposed [1]. Directional communication utilizes antennas that can transmit to specific directions with limited angles. Due to these properties, a well-designed network utilizing directional antennas allows spatial reuse that could not be achieved with omni-directional antennas. Using directional antennas, more nodes can transmit their simultaneously without causing interference to each other.

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Although directional antennas can improve the spatial usage and resolve some interference problems, interference problems are still not fully solved and transmission failures can occur in the limited regions of the transmission of directional antennas. This can be alleviated by using the concept of Wireless Broadcast Advantage (WBA) [2], which is a theory that all transmission in the wireless medium is based on broadcasting by nature. WBA makes it possible to listen to the ongoing transmission of the network if the nodes are within the communication range, even if the transmissions are not destined for them. Using this theory, cooperative protocols can be designed to alleviate transmission failure problems.

Cooperative routing [1] utilizes this property and forms a cooperative group within the region of neighbor nodes. These groups listen to ongoing transmissions and forwards data to the destination if needed. Also, the nodes can cooperative to perform synchronization between the sender and receiver. The synchronization process is a complex physical layer process and should be devised properly to have the advantage of it.

In routing protocols, the loss of data packet or failed communication should be marked as a route error and error message should be sent to source so that the source can find the fresh route. In AODV [3], this process is enhanced with the local repair. This allows the intermediate relay nodes to initiate a new local route to the destination. This information need not be sent to the source node as it is not affecting the current transmission. If the local repair is disabled then the relay node generates the error message and transmits it to the source. This will initiate the discovery of the fresh route. In the mean time the packets which were not delivered will be dropped. To find the fresh route or repair the damaged route precious resource and time will be wasted for delivery of the packet. To alleviate this problem, cooperative routing can be utilized.

In this paper we design the Collaborative Routing Protocol (CORP) in a wireless multi-hop environment with directional antennas. In this protocol we utilize the WBA to relay the packets to the destination by sensing the failure in the current transmission. The process is similar to the work by S. Biswas et al [4], in opportunistic routing, where the group of nodes contributes their available resources to relay the packet to the destination. Their research was basically focused on broadcasting the packet and then letting the receiver of this packet locally choose the relay nodes among them by calculating the distance towards the destination. However, the fundamental information that the node needs to have before initiating the transmission is the location information of the destination node. In our protocol we create the routing path before the actual data transmission which is similar to the route discovery process in AODV. The packet transmission is done after receiving the correct path from the destination via route reply message.

II. Related Works

Researches on wireless multi-hop networks in recent years have been focused on how to effectively automate the organization of the network. In such networks the devices communicate with other wireless devices in a peer-to-peer fashion without the need for pre-existing infrastructures. The name "Ad Hoc networks" is viewed as the network that can be established "on the fly" [5]. This paper also gives the fundamental work connectivity of the wireless multi-hop networks.

There have been several researches on effective routing protocols that focus on addressing the problem of wireless networks. The concept of opportunistic routing also gives the glimpse of the possibilities of using the neighboring nodes to perform better routing [6] with location awareness. This will help the packet be transmitted to longer distances than what the traditional routing protocols can achieve. However, this leaves the condition where the recent change in the medium cannot be known to the sender at that particular moment. Therefore, the chosen node may not be available due to the error in the transmission range or node failure. In this situation, the packet is lost and the precious calculation efforts are also wasted.

Another similar work by S. Biswas et. al.[4] provides opportunity for the neighboring nodes to choose the next relay nodes. The forwarding node set, which is the group of nodes with similar properties, chooses to forward the packet to the next hop if they are near the destination and have better delivery probability. The algorithm chooses one of the nodes from the forwarding node set to forward the packet. Their findings were promising by giving the opportunity for nodes to forward the packets that are near the destination which otherwise would have not been a part of the communication. The work can be managed with the directional communication by finding the location of the forwarding set to the destination. With the use of directional communication we can reutilize the available spectrum in the network for a concurrent transmission.

Recent development on this area of research is focused on multi-rate, anypath or hybrid wireless networks to have better response from the network with increased performance in terms of throughput, delivery ratio, decreased in delay. In [7], R. Laufer et al have utilized the available transmission rates available by the wireless devices to forward the packets within the given forward node sets. The paper suggests that whenever possible, the available transmission rate is utilized for the transmission. The performance as shown in their research gives the idea that the multi-rate environment can be implemented with the condition that the path is shortest to the destination. They have named their research as shortest multirate anypath. Considering the throughput with the traditional fixed rate routing, this scheme is better but with the cost of the time which is required for the negotiation of the TX rate by the two nodes according to the condition of the environment at the time of transmission.

X. Wang et. al. [8] uses the terminology of collaborative routing with reference to their work in cross layer optimization approach for spectrum allocation and transmission scheduling. They present their cross layer approach to produce a schedule for packets in the network by looking at the resources from the link layer. Their result shows that they have link layer scheduling through which the routing is optimized for the wireless ad hoc networks. Thus, their protocol increases the system performance significantly by balancing the load over different channels and times.

In all of the researches described above, the main focus of the work is to achieve better routing performance from available paths. All of these works operate within the scenario where all nodes are active and their task is to find the better route among them. They have mainly used packet broadcast to let the neighbor node decide the next forwarding node which has its own demits such as large number of same data packets in the network waiting for the transmission to the next reliable node. We have chosen the process of finding the route before the transmission of the packet so that the shortest path to the destination is known to the source node. All of our work in this paper is based on these pre-existing routing paths.

III. A Collaborative Routing Protocol (CORP)

Our protocol is divided into two distinct phases: route discovery process and the route failure process.

A. Network Model

The nodes in our network are placed in the grid topology of 1500m x 1500m. Each node is equipped with directional antenna having 60degree sector. The transmission range and reception range is fixed to 200m. Directional HELLO messages are used to find the neighboring nodes and also their respected sectors through which they are able to see each other. All the nodes use directional antenna for transmission and reception. RREQ and RREP messages are modified to include the sector information of the directional antenna. RREP value is also added with the RSS value that is received from MAC layer. When the node is not transmitting, it will be switched to the receiving mode and start listening from all the sectors by sweeping through each sector in a round robin fashion. Nodes are free to communicate with each other via respected sectors. All the nodes are static and prone to interferences so that it can fail during the simulations. This will create an unstable network environment for our CORP to perform. Each of the nodes within the routing path will create yet another routing table known as collaborating routing table (CRT) for logging all the information about the collaborating nodes.

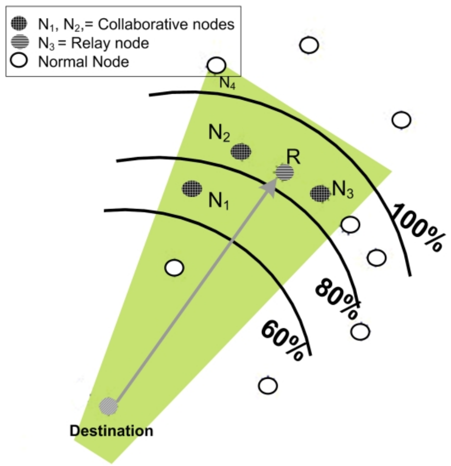
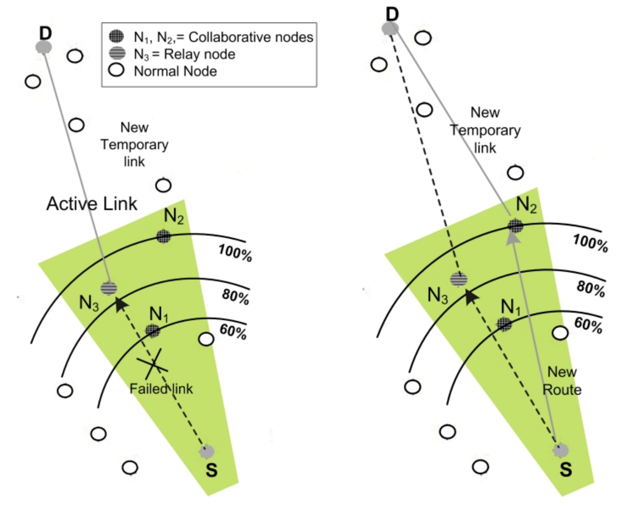


Figure 1: Route Reply process in CORP utilizing WBA with directional antenna



a) Failed link detected by WBA b) Route recovery

Figure 2: Collaborating Route with directional antenna

B. *Route Discovery Process*

Each node needs to send HELLO messages from all the sectors i.e. six. The HELLO message is modified to include the sector information and 1-hop neighbor information. Each of these HELLO messages will be received by the neighbors and processed to create a neighbor table. The neighbor table includes the neighbor information including the sector with which it is going to communicate. Once the node is ready for the transmission of data packets, the route discovery process is initiated.

When the node gets the data to transmit to the network from the application layer, the source node should initiate the route discovery process. The modified Route Request (RREQ) message of CORP contains the sectored information of the sender to ease the identification process by the correct receiver. Unlike omni-directional antenna, directional antenna needs sectored information to identify the active source of the packet. RREQ is also transmitted to all the sectors of the directional antenna in a round robin fashion. The receiving nodes will also receive this information via directional antennas. The node will be sweeping all the receiving sectors in a round robin fashion so that it can detect any transmission directed towards it. The receiving node captures the transmission and will lock itself to complete the reception. The RREQ packet is further relayed to its neighbors till the destination node is reached. If the receiver misses the transmission at first sweep then it need to wait till the next transmission of the packet. The transmission should be long enough so that the next sweep does not miss the transmission. There is a possibility of receiving multiple RREQ packets via different directional antennas. This will not require multiple RREP packets to send as the node checks the RREP sequence to verify the no duplicate RREQ's are processed.

Once the destination is reached, the modified RREP message is generated and sent back to the source by retracing its path, shown in Figure 1. The sector information and the RSS value received from MAC layer are included in the RREP packet. The intermediate nodes within the transmission range of the sender of these RREP packets will be updating its collaborating routing table (CRT). This CRT contains multiple paths to the destination with sectored information of the directional antenna given by RREP. Due to the wireless broadcast advantage (WBA), the nodes, N_1, N_2, and N_3 that are within the transmission range of the RREP can also listen to this transmission. These nodes are termed as collaborating nodes. These collaborating nodes are categorized according to the received signal strength (RSS) value. The maximum RSS value, embedded in the RREP value, is the maximum transmission range of the source node. The RSS value recorded inside the RREP is recorded in the CRT for future reference.

C. *Route Recovery Process (Collaboration Process)*

When the node receives data from the application layer, it will unicast packets to N_3 since it is the routing path to the destination. We have utilized the lower layer message exchanges to receive the hop-by-hop acknowledgement so that the collaborating nodes will realize that successful data transmission has occurred between the intermediate nodes. The block diagram of this process can be seen in figure 3. If the node overhears the current communication, it first checks the packet for the acceptable RSS range, the reference given by the value in the RREP packet. Then node N_1 and N_2 will buffer the packet or else drop it.

During the data transmission, if the collaborating nodes do not hear the hop-by-hop acknowledgement from lower layers, then this particular 1-hop data transmission to the relay node N_3 from the source S is assumed to be lost and the link and/or node is rendered failed as shown in figure 2(a). Therefore, the collaborating nodes will not attempt to send the packet to the next hop/destination. The problem at this point will be to choose an alternative relay node. CORP uses the RSS value and the timer function to select the new relay node among the collaborating nodes. The nodes will select the timer by (RSS_{ref} – RSS_r) * RANDOM_NUMBER where RSS_{ref} is the referenced RSS value acquired from RREP message and RSS_r is the received signal strength. RANDOM_NUMBER is the number reserved for the group. 80%~100% groups will be having smaller timer function whereas 60%~80% groups will have larger timer. Therefore, the timer of the 80%~100% groups expires early, and gains more chance to start the

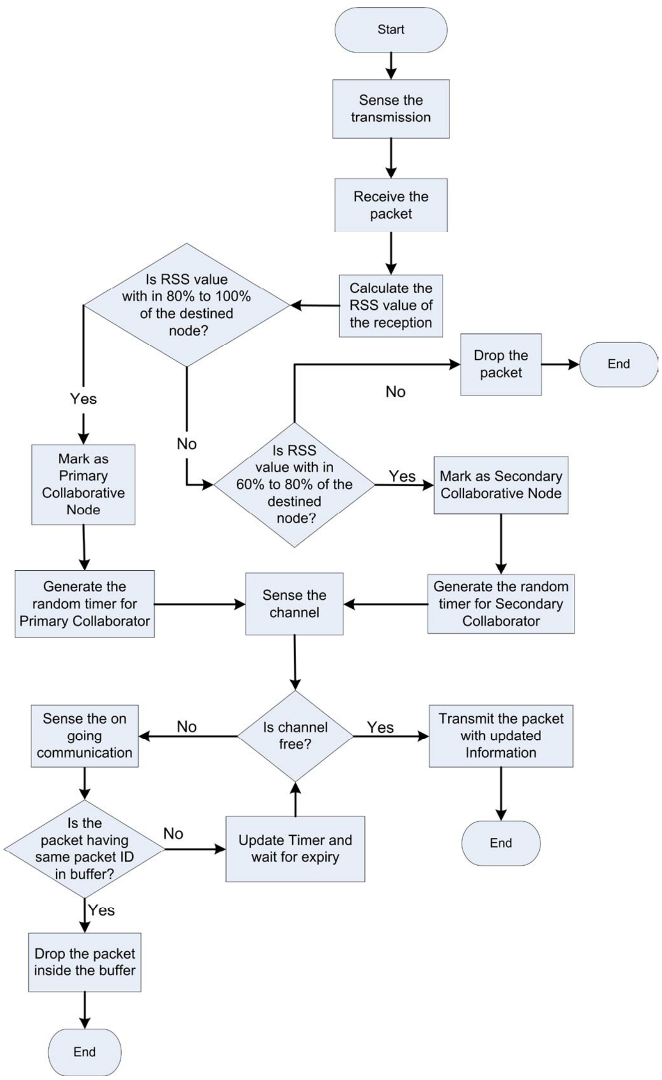


Figure 3: Collaborating Routing Protocol Process

transmission. The chosen relay node from the collaborating nodes is the one which is the most distant one among them from the source node.

Once the new relay node is chosen after the expiry of the timer, the node will modify the information of the packet and update the packets stored inside the buffer that will be sent to the destination. Unlike the local repair in AODV, CORP uses collaboration among the nodes to relay the packet to the destination or next hop. The next hop or destination information is checked from the CRT. Then local repair of the route is initiated to find the route to the destination from this failed path onwards. The data packet is delayed in an attempt for a local relay. If the local relay fails then the route error (RERR) message is sent to all the dependents of that node and marks the link as a failed link. However, the route may be broken at that particular point of the route but the remaining path could still be valid. To avoid this, the route error message is generated and the packet is dropped, abandoning the rest of the route. The collaborating nodes will utilize this particular situation to prevent the loss of the data or further flooding of the control packets to the network. The summary of the process is shown in Figure 3.

The failure of the hop-by-hop acknowledgement of the data transmission by the lower layer network stack will indicate the collaborative nodes of the link and/or node failure. Once the expected time for the acknowledgement is expired then these collaborating nodes will choose any among them to take over the communication and relay the data packet to the destination. The selection of the suitable node could depend upon the various factors. In our paper we have considered the RSS value to choose the suitable collaborating node. The range of the RSS value is selected as 60% to 80% and 80% to 100%. The collaborating nodes within the 80% to 100% will be getting higher priority to take over the communication rather than the nodes within the 60% to 80% range. If there are no other nodes within the 80% to 100% range then the lower priority nodes will try to finish the communication.

Once the collaborating node is chosen it will require putting the data packet to its buffer and then start taking control of the communication for the time being. This process could be continued until the failed link/node is recovered. During this time no route error message is generated and the network is not affected by the failure of the node and/or link. Only the intermediate relay or the destination is informed about this temporarily arrangements. The immediate node within the routing path should be informed about the changes in the relay nodes so that the functions in the data receiving section are modified accordingly. This will help reduce the waiting time for the packet before getting an active route. In CORP, the waiting time is reduced as the intermediate collaborating node initiates the routing of the buffered packet so that the packets are received with little and/or no delay. This change is not permanent as fresh RREQ message is sent to recover the path or the old relay node can recover to take over its position again.

IV. Performance Evaluation

For the simulation, we have used the following system environment to simulate the CORP. Wide variety of system parameters are used for evaluation in wireless multi-hop network which is described in environment and parameters.

A. Environment and Parameters

Our protocol is designed for the system prone to the node failure or interferences from the neighbor nodes. We have used Qualnet 4.5 simulator [9]. The network is simulated 1500mx1500m with 5x5 nodes. Grid topology is used with the directional antenna with similar transmission and reception range.

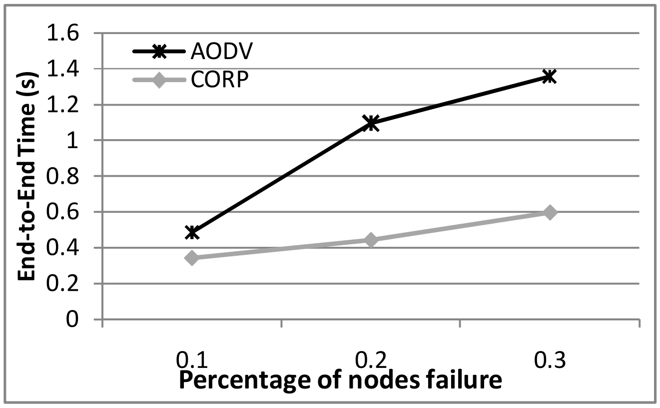


Figure 4: End-to-End delay with percentage of Nodes prone to failure in 5x5 nodes

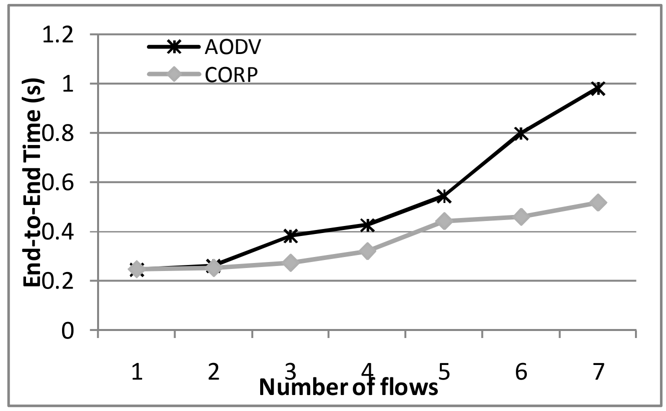


Figure 5: End-to-End delay vs. Number of flows in 5x5 nodes

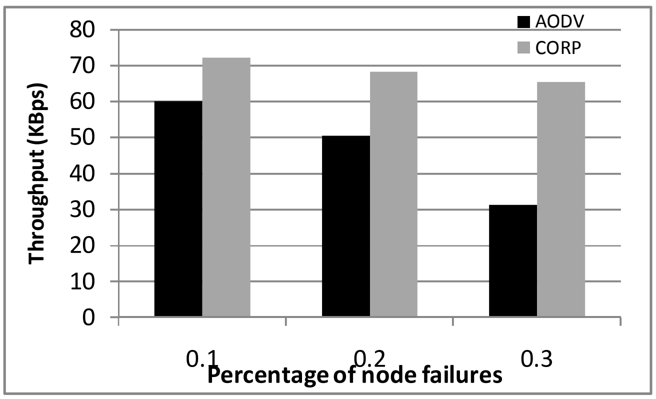


Figure 6: Aggregate CBR throughput vs. probability of the node failures in 5x5 grid topology

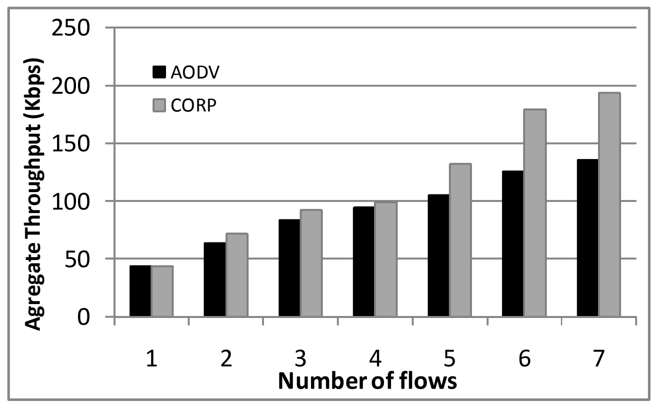


Figure 7: Aggregate CBR throughput vs. Number of flows in 5x5 nodes

Each node is equipped directional antenna with 60 degree sectors. These parameters are fixed for the entire life of the network. We have used IEEE 802.11b radio parameters with 2Mbps data rate. The interlayer communications for the RSS values are taken by IEEE PHY_802.11. The MAC is tuned with the routing layer to exchange the control messages for the RSS values and packet acknowledgement information. CBR traffic is used with generating 10packets per second.

The evaluation of the CORP is compared with the AODV routing protocol. Both CORP and AODV use RREQ, RREP and RRER control messages for the discovering the route, replying the route as well as sending the route error message. Both are table driven routing protocols. However, it CORP is distinguishable in that it uses collaborative routing table (CBT) to keep the log of the alternate routes to the destination. The noise is artificially introduced in the links to simulate a broken link environment. Also, the nodes are preset with failures so that CORP can function properly to its full potentials.

B. Simulation Results

First of all we would like to present the end-to-end delay experienced by a packet after successful transmission. We have used 2 different parameters to compare the results among AODV and our protocol, CORP. First we have forced random nodes to fail so that node failures are simulated at particular locations. We have used multiple flows in here and remain same for the calculations. This allows the neighboring nodes to go into collaboration mode and attempt to recover the failed communication at that particular location. We have used 10%, 20% and 30% of the nodes to fail at different times so that there will be constant attempt to recover failed communication in the network. For 10% of the failed nodes, both AODV and CORP had almost similar end-to-end delay. As the number of failed nodes increase, the failed communication links also increases. This thus adds on delay to the packet to wait for the good communication links for packet transmission. The maximum average delay experienced by the packet is about 1.4sec in AODV. With the CORP the end-to-end delay is also increased but the degradation is not as severe as that of the AODV. The maximum variation in this variable is almost doubled as shown in Figure 4.

Figure 5 shows the effect of the number of flows in both AODV and CORP protocol. We have put 10% node failure for this scenario. This will raise the increased failed communication due to the interferences from multiple flows passing through an identical node. This also causes additional delay in the network as nodes have to wait for the channel to clear channel before transmitting the packet. This waiting time adds up to the end-to-end delay in the overall transmission. As number of flows increase, the end-to-end delay also increases in AODV and CORP, but the variation of CORP is not as steep as that of the AODV. For AODV, as the number of flow increases, there is a probability that there might be some interference to the ongoing transmissions. As shown in figure 5, the end-to-end delay is increased with the increase in the number of concurrent flows in the neighbors. The main reason of the increase in AODV is due to the fact that the ongoing communication within the neighbors is causing more transmissions to fail. AODV tries to revive the path to the destination by local repair. This causes the packet to experience a delay in transmission thus increasing more end-to-end delay. In the case of CORP, the failed communication is handled by the collaborating nodes so that the failed node or failed link is bypassed to send the packet to the destination. The delay is increased steadily until the maximum interface is reached. When this value is bypassed, the delay is suddenly increased but still below the values given by AODV.

Figure 6 shows response of the node failure in the network in terms of throughput. As the network set to be prone to the node failure, we have set 10%, 20% and 30% nodes will be failed during the simulation. The simulation results show that the node failure in AODV is not good. The failure of the node frequently issues RERR/ RREQ packet to find the fresh route for the packets adding delay to the packet transmission. Whereas the CORP will avoid the use of RREQ packet for fresh route rather it will use WBA to listen to the ongoing transmission and then will forward the packet if required as seen in this situation. These collaborating nodes will re-route the packet to the destination avoiding the path to the failed node/link. This will save the packet drop thus increasing the throughput and decreasing the end-to-end delay. The figure 6 shows that CORP performed little better than that of the AODV.

Our final figure 7 shows the number of broken links experienced by AODV and CORP. Since there are variations in the traffic due to the number of flows, then it is obvious that the interference will also change. The affect of the interference in the neighbors gives the broken links to the available source destination path. The number of broken links that we have recorded is for the different source destination pair with varied hop counts. It is clearly shown in the figure 8 that as the number of flows increase, the number of broken links are also increased in both the AODV and CORP. The amount of increase in the broken links is larger in AODV than in CORP. There are still broken links in CORP due to static channel assignment the entire network. We have used single channel to the entire network. Dynamic channel assignment with the directional antenna does not lie within the scope of this paper.

The overall performance of the CORP suggests that the collaboration among the neighboring nodes does significantly help to improve the performance of the network prone to node/link failure. The work might look similar to the opportunistic routing but in the opportunistic routing the construction of the route is does with the help of the node collaboration whereas in CORP we are not constructing the route in the first hand. We are only using the available routing path constructed from the proactive routing protocols such as AODV and implement our collaborative routing. The comparison of the AODV and CORP, the CORP performed better due to the collaboration among the node when required.

V. Conclusion

We have shown that utilizing the concept of WBA can be useful. Proper utilization of overhearing concurrent transmission can be used to collaborate among the nodes to achieve better performance. The use of directional antenna over the classical antennas gives the better utilization of spatial reuse of channels among the available ones. This will give an extra benefit to the network performances. We have also shown that the end-to-end delay of the packet is largely reduced and almost constant with our protocol whereas for the AODV routing protocol it increases as the flow increases. If an artificial interference is inserted to the network, CORP also gives less end-to-end delay in comparison to the AODV. CORP gives the required end-to-end delay response with the collaboration among the neighboring nodes to tackle faulty nodes or faulty links.

The future extension of the paper will include mobility among the nodes. Since mobile nodes in the wireless network experience frequent link failures, it requires frequent and more effective route discovery process. If the node within the neighbor of the mobile node can collaborate with each other then it can improve the performance of the network. We are also considering the affect of considering more than one type of antenna for collaboration. These environments are realistic for the multi-hop wireless networks.

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