

Autonomous Reconfiguration for Wireless Mesh Network

B.Sindhu*, V.Bharathi**, N.Karthikeyan***

Department of Electronics and Communication Engineering,
Sri Manakula Vinayagar Engineering College, Madagadipet

ABSTRACT

The demands for the network usage are increasing day by day. During their lifetime, multihop wireless mesh networks (WMNs) experience frequent link failures caused by channel interference, dynamic obstacles, and/or applications' bandwidth demands, which may degrade the system performance. This paper presents an autonomous network reconfiguration system (ANRS) that enables a multiradio WMN to autonomously recover from local link failures to preserve network performance. Using ANRS necessary changes are made in local and radio channel assignments for failure recovery. Next, based on the thus-generated configuration changes, the system cooperatively reconfigures network settings among local mesh routers. ANRS has been implemented extensively on our IEEE 802.11-based WMN through ns2-based simulation. Our evaluation results show that ANRS outperforms existing failure-recovery schemes in improving channel-efficiency and in the ability of meeting the applications' bandwidth demands.

Keywords-IEEE 802.11, multiradio wireless mesh networks (mr-WMNs), Routing, self-reconfigurable networks, wireless link failures.

1. INTRODUCTION

Wireless mesh networks are boon to the wireless architecture. It supports larger applications and it provides several benefits to users such as, no cabling cost, automatic connection to all nodes, network flexibility, ease of installation and it also discovers new routes automatically. These wireless mesh networks are not stand alone it is compatible and interoperable with other wireless networks. It provides greater range of data transfer rates.

Wireless mesh networks are preferable compared to the adhoc networks for the easy of network maintenance, robustness etc. Wireless mesh networks[1] often consist of mesh clients, mesh routers and gateways. The mesh clients are often laptops, cell phones and other wireless devices while the mesh routers forward traffic to and from the gateways which may but need not connect to the Internet.

The coverage area of the radio nodes working as a single network is sometimes called a mesh cloud. Access to this mesh cloud is dependent

on the radio nodes working in harmony with each other to create a radio network. A mesh network is reliable and offers redundancy. When one node can no longer operate, the rest of the nodes can still communicate with each other, directly or through one or more intermediate nodes. A wireless mesh network can be seen as a special type of wireless ad-hoc network. A wireless mesh network often has a more planned configuration, and may be deployed to provide dynamic and cost effective connectivity over a certain geographic area.

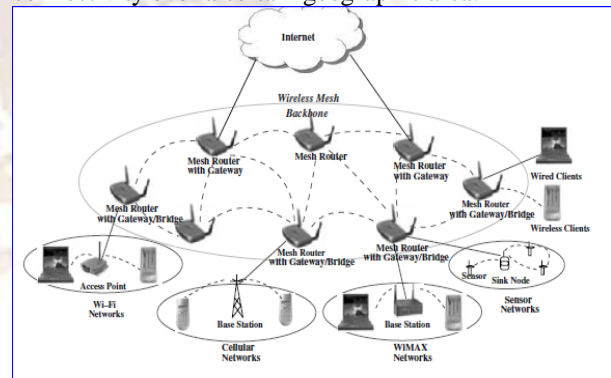


Fig.1 wireless mesh network

Wireless mesh networks (WMNs) are being developed actively and deployed widely for a variety of applications, such as public safety, environment monitoring, and citywide wireless Internet services. They have also been evolving in various forms (e.g., using multiradio /channel[2] systems to meet the increasing capacity demands by the above-mentioned and other emerging applications. However, due to heterogeneous and fluctuating wireless link conditions preserving the required performance of such WMNs is still a challenging problem.

For example, some links of a WMN may experience significant channel interference from other coexisting wireless networks. Some parts of networks might not be able to meet increasing bandwidth demands from new mobile users and applications. Links in a certain area (e.g., a hospital or police station) might not be able to use some frequency channels because of spectrum etiquette or regulation. Wireless mesh networks does not provide centralized trusted architecture too, to distribute the public keys. Here in the wireless mesh network, mesh clients should contain power efficient protocols. Mesh routers in the wireless

mesh networks perform dedicated routing and configurations.

2. RELATED WORK

Even though many solutions for WMNs to recover from wireless link failures have been proposed, they still have several limitations as follows. First, resource-allocation algorithms can provide (theoretical) guidelines for initial network resource planning. However, even though their approach provides a comprehensive and optimal network configuration plan, they often require “global” configuration changes, which are undesirable in case of frequent local link failures. Next, a *greedy* channel-assignment algorithm can reduce the requirement of network changes by changing settings of only the faulty link(s). However, this greedy change might not be able to realize full improvements, which can only be achieved by considering configurations of neighbouring mesh routers in addition to the faulty link(s). Third, fault-tolerant routing protocols, such as local rerouting or multipath routing can be adopted to use network-level path diversity for avoiding the faulty links. However, they rely on detour paths or redundant transmissions, which may require more network resources than link-level network reconfiguration.

2.1 CHANNEL ASSIGNMENT ALGORITHM

Channel assignment and scheduling algorithms provide holistic guidelines, such as throughput bounds and schedulability for channel assignment during a network deployment stage. However, the algorithms do not consider the degree of configuration changes from previous network settings, and hence they often require global network changes to meet all the constraints. Even though these algorithms are suitable for static or periodic network planning, they may cause network service disruption, and thus are unsuitable for dynamic network reconfiguration that has to deal with frequent local link failures.

The greedy channel-assignment algorithm, which considers only local areas in channel assignments, might do better in reducing the scope of network changes than the channel assignment algorithms. However, this approach still suffers from the ripple effect, in which one local change triggers the change of additional network settings at neighboring nodes due to association dependency among neighboring radios. This undesired effect might be avoided by transforming a mesh topology into a tree topology, but this transformation reduces network connectivity as well as path diversity among mesh nodes.

Interference-aware channel assignment algorithms[3] can minimize interference by assigning orthogonal channels as closely as possible geographically. While this approach can

improve overall network capacity by using additional channels, the algorithm could further improve. These algorithms may require global network configuration changes from changing local QoS demands, thus causing network disruption.

3 PROPOSED SYSTEM

To overcome the above limitations, we propose an autonomous network reconfiguration system (ANRS) that allows a multiradio WMN (mr-WMN) to autonomously reconfigure its local network settings—channel, radio, and route assignment—for real-time recovery from link failures[5]. In its core, ANRS is equipped with a reconfiguration planning algorithm that identifies local configuration changes for the recovery while minimizing changes of healthy network settings.

Briefly, ANRS first searches for feasible local configuration changes available around a faulty area, based on current channel and radio associations. Then, by imposing current network settings as constraints, ANRS identifies reconfiguration plans that require the minimum number of changes for the healthy network settings. Next, ANRS also includes a monitoring protocol that enables a WMN to perform real-time failure recovery in conjunction with the planning algorithm. The accurate link-quality information from the monitoring protocol is used to identify network changes that satisfy applications’ new QoS demands or that avoid propagation of QoS failures to neighboring links (or “ripple effects”). Our evaluation results show that ANRS outperforms existing failure-recovery methods, such as static or greedy channel assignments, and local rerouting[4].

First, ANRS’s planning algorithm effectively identifies reconfiguration plans that maximally satisfy the applications’ QoS demands. Next, ANRS avoids the ripple effect via QoS-aware reconfiguration planning, unlike the greedy approach. Third, ANRS’s local reconfiguration improves network throughput and channel efficiency by more than 26% and 92%, respectively, over the local rerouting scheme. The routing messages are being transmitted from the source node to the destination in order to find the least cost path. These routing messages should at least carry one ticket regularly.

3.1 Overall modules of ANRS

The overall modules of ANRS system are,

- i. Network construction
- ii. Link-State
- iii. Group organizer
- iv. Failure detector
- v. Gateway planner
 - a. Plan generator
 - b. QOS filter
- vi. benefit filter
- vii. Optimal Analyser

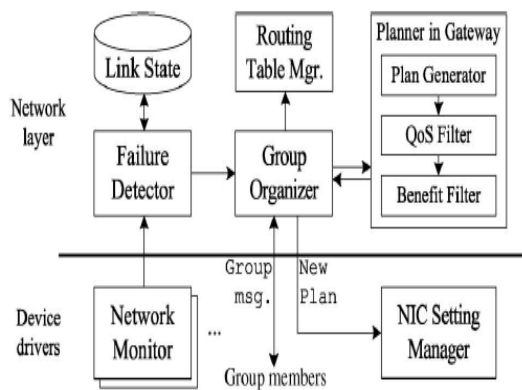


Fig 2: ANRS software architecture

A. Network Construction

In this module, construct the network as cluster form. It store the node name, data rate and it also maintain the Information about the neighbouring nodes .Gateway also involved in it. It will be make detection of route as better.

B. Link State

Every node monitors the quality of its outgoing wireless links. The node contains information about the incoming and outgoing traffic. It maintains the information about the neighbouring nodes. It measures wireless link conditions via a hybrid link quality measurement technique.

C. Group Organizer

It forms a local group among mesh routers. Each router has a specific set of locations from which it can accept data, and a specific set of locations to which it can send data. Mesh routers work by continuously monitoring network activity and maintaining lists of other devices in their vicinity.

D. Failure Detector

It interacts with an network monitor in the device driver and maintains an up-to-date link-state table. Network monitor, monitors link-quality and extensible to support as many multiple radios as possible.

E. Gateway Planner

Network Planner: It generates needed reconfiguration plans only in a gateway node.

QoS Planner: ARS applies strict constraint to identify a reconfiguration plan that satisfies the QoS demands and that improves network utilization most.

Benefit Filter: It identifies, which reconfiguration plans are suitable to reach destination.

F. Optimal planner

It identifies, which reconfiguration plan having the shortest path to reach destination. Identifies reconfiguration plans that require the minimum number of changes for the healthy network settings.

3.2 Planning for localized reconfiguration

The core function of ANRS is to systematically generate localized reconfiguration plans. A reconfiguration plan is defined as a set of links' configuration changes (e.g., channel switch, link association) necessary for a network to recover from a link(s) failure on a channel, and there are usually multiple reconfiguration plans for each link failure.



Fig 3: Localized reconfiguration planning in ANRS

Existing channel-assignment and scheduling algorithms seek “optimal” solutions by considering tight QoS constraints on all links, thus requiring a large configuration space to be searched and hence making the planning often an NP-complete problem.

In addition, change in a link's requirement may lead to completely different network configurations. By contrast, ANRS systematically generates reconfiguration plans that localize network changes by dividing the reconfiguration planning into three processes—feasibility, QoS satisfiability, and optimality—and applying different levels of constraints.

As depicted in Fig. 3, ANRS first applies connectivity constraints to generate a set of feasible reconfiguration plans that enumerate feasible channel, link, and route changes around the faulty areas, given connectivity and link-failure constraints.

Then, within the set, ANRS applies strict constraints (i.e., QoS and network utilization) to identify a reconfiguration plan that satisfies the QoS demands and that improves network utilization most. It also generates feasible plan for reconfiguration and also provide QoS satisfiability evaluation for better results.

3.2.1 Feasible Plan Generation:

Generating feasible plans is essentially to search all legitimate changes in links' configurations and their combinations around the faulty area. Given multiple radios, channels, and routes, ANRS identifies feasible changes that help avoid a local link failure but maintain existing network connectivity as much as possible. However, in generating such plans, ANRS has to address the following challenges.

1) Avoiding a faulty channel:

ANRS first has to ensure that the faulty link needs to be fixed via reconfiguration. To this end, ANRS considers three primitive link changes Specifically, to fix a faulty link(s), ANRS can use: A) a channel-switch where both end-radios of link AB can simultaneously change their tuned channel;B) a radio-switch where one radio in node A can switch its channel and associate with another radio in node B; C) a route-switch where all traffic over the faulty link can use a detour path instead of the faulty link.

TABLE 1
Link changes in ANRS

Primitive changes	Description
Channel switch ($S(A_i, B_j)_{\alpha \rightarrow \beta}$)	Radios A_i and B_j of link AB switch their channel (α) to other channel (β).
Radio switch ($R(A_i, B_j)_{\alpha \rightarrow \beta}$)	Radio A_i in node A re-associates with radio B_j in node B , tuned in channel (β).
Detouring ($D(A_i, B_j)$)	Both radios A_i and B_j of link AB remove their associations and use a detour path, if exists.

2) Maintaining network connectivity and utilization:

While avoiding the use of the faulty channel, ANRS needs to maintain connectivity with the full utilization of radio resources. Because each radio can associate itself with multiple neighboring nodes, a change in one link triggers other neighboring links to change their settings. To coordinate such propagation, ANRS takes a *two-step* approach.

ANRS first generates feasible changes of each link using the primitives, and then combines a set of feasible changes that enable a network to maintain its own connectivity. Furthermore, for the combination, ANRS maximizes the usage of network resources by making each radio of a mesh node associate itself with at least one link and by avoiding the use of same (*redundant*) channel among radios in one node.

3) Controlling the scope of reconfiguration changes:

ANRS has to limit network changes as *local* as possible, but at the same time it needs to find a locally optimal solution by considering more network changes or scope. To make this tradeoff, ANRS uses a *-hop* reconfiguration parameter. Starting from a faulty link(s), ANRS considers link changes within the first hops and generates feasible plans. If ANRS cannot find a local solution, it increases the number of hops so that ANRS may explore a broad range of link changes. Thus, the total number of reconfiguration changes is determined on the basis of existing configurations around the faulty area as well as the value of k .

3.3 NEED FOR SELF-RECONFIGURABILITY

Maintaining the performance of WMNs in the face of dynamic link failures remains a challenging problem. However, such failures can be withstood (hence maintaining the required performance) by enabling mr-WMNs to autonomously reconfigure channels and radio assignments, as in the following examples.

i) Recovering from link-quality degradation:

The quality of wireless links in WMNs can degrade (i.e., link-quality failure) due to severe interference from other collocated wireless networks. For example, Bluetooth, cordless phones, and other coexisting wireless networks operating on the same or adjacent channels cause significant and varying degrees of losses or collisions in packet transmissions. By switching the tuned channel of a link to other interference-free channels, local links can recover from such a link failure.

ii) Satisfying dynamic QoS demands:

Links in some areas may not be able to accommodate increasing QoS demands from end-users (QoS failures), depending on spatial or temporal locality. For example, links around a conference room may have to relay too much data/video traffic during the session. Likewise, relay links outside the room may fail to support all attendees' voice-over-IP calls during a session break. By reassociating their radios/channels with underutilized radios/channels available nearby, links can avoid communication failures[6].

iii) Coping with heterogeneous channel availability:

Links in some areas may not be able to access wireless channels during a certain time period (spectrum failures) due to spectrum etiquette or regulation. For example, some links in a WMN need to vacate current channels if channels are being used for emergency response near the wireless links (e.g., hospital, public safety). Such links can seek and identify alternative channels available in the same area.

Motivated by these three and other possible benefits of using reconfigurable mr-WMNs, in the remainder of this paper, we would like to develop a system that allows mr-WMNs to autonomously change channel and radio assignments (i.e., self-reconfigurable) to recover from the channel-related link failures.

3.4 QoS-satisfiability Evaluation

Among a set of feasible plans, ANRS now needs to identify QoS-satisfying reconfiguration plans by checking if the QoS constraints are met

under each plan. Although each feasible plan ensures that a faulty link(s) will use non faulty channels and maintain its connectivity, some plans might not satisfy the QoS constraints or may even cause cascaded QoS failures on neighboring links. To filter out such plans, ANRS has to solve the following challenges.

1) Per-link bandwidth estimation:

For each feasible plan, ANRS has to check whether each link's configuration change satisfies its bandwidth requirement, so it must estimate link bandwidth. To estimate link bandwidth, ANRS accurately measures each link's capacity and its available channel airtime. In multihop wireless networks[8] equipped with a CSMA-like MAC, each link's achievable bandwidth (or throughput) can be affected by both link capacity and activities of other links that share the channel airtime.

Even though numerous bandwidth-estimation techniques have been proposed, they focus on the average bandwidth of each node in a network or the end-to-end throughput[7] of flows which cannot be used to calculate the impact of per-link configuration changes. By contrast, ANRS estimates an individual link's capacity based on measured (or cached) link-quality information—packet-delivery ratio and data-transmission rate measured by passively monitoring the transmissions of data or probing packets.

Here, we assume that ANRS is assumed to cache link-quality information for other channels and use the cached information to generate reconfiguration plans. If the information becomes obsolete, ANRS detects link failures and triggers another reconfiguration to find QoS-satisfiable plans.

2) Examining per-link bandwidth satisfiability :

Given measured bandwidth and bandwidth requirements, ANRS has to check if the new link change(s) satisfies QoS requirements. ANRS defines the expected busy airtime ratio of each link to check the link's QoS satisfiability.

3) Avoiding cascaded link failures:

Besides the link change, ANRS needs to check whether neighboring links are affected by local changes (i.e., cascaded link failures). To identify such adverse effect from a plan, ANRS also estimates the QoS satisfiability of links one hop away from member nodes whose links' capacity can be affected by the plan. If these one-hop-away links still meet the QoS requirement, the effects of the changes do not propagate thanks to spatial reuse of channels. Otherwise, the effects of local changes will propagate, causing cascaded QoS failures.

3.5 Choosing the Best Plan

ANRS now has a set of reconfiguration plans that are QoS-satisfiable and needs to choose a plan within the set for a local network to have evenly distributed link capacity. However, to incorporate the notion of fair share into the planning, ANRS needs to address the following challenges.

- i. Quantifying the fairness of a plan
- ii. Breaking a tie among multiple plans

i) Quantifying the fairness of a plan:

ANRS has to quantify the potential changes in link-capacity distribution from a plan. To this end, ANRS defines and uses a benefit function that quantifies the improvement of channel utilization that the reconfiguration plan makes. Specifically, the benefit function is defined as , the relative improvement in the airtime usage of radio , and the number of radios whose has changed from the plan. This definition allows the benefit function to quantify the overall change in airtime usage, resulting from the reconfiguration plan.

ii) Breaking a tie among multiple plans:

Multiple reconfiguration plans can have the same benefit, and ANRS needs to break a tie among them. ANRS uses the number of link changes that each plan requires to break a tie. Although link configuration changes incur a small amount of flow disruption (e.g., in the order of 10 ms) the less changes in link configuration, the less network disruption.

ANRS favors a plan that reconfigures links to have 50% available channel airtime. If a plan reconfigures a WMN to make the links heavily utilized while idling others (e.g., plan 2), then the benefit function considers the plan ineffective, placing the plan in a lowly ranked position.

4. Performance Evaluation

ANRS effectively reconfigures the network on detection of a failure, achieving more bandwidth than static assignment and local rerouting. ANRS accurately detects a link's QoS-failure using link-quality monitoring information and completes network reconfiguration. ANRS also improves channel efficiency. ANRS identifies feasible changes that help avoid a local link failure but maintain existing network connectivity as much as possible. ANRS is implemented as an agent in both the MAC layer and a routing protocol. It periodically collects channel information from MAC and requests channel switching or link-association changes based on its decision. At the same time, it informs the routing protocol of network failures or a routing table update.

The simulation topology is set up to analyze the performance of ANRS. It is also expected that the ANRS effectively reconfigures the network around a faulty link improving both network throughput and channel efficiency. By contrast local rerouting causes degradation in the channel efficiency due to the use of a detour path. The performance parameters that can be obtained through the NS2 Trace Analyser are as follows

- Throughput
- Channel efficiency
- Delay

Throughput: Throughput is the rate at which a network sends and receives data. Throughput is rated in terms bits per second (bit/s). Throughput, $T_p = P_a / P_f$, P_a = packets received, P_f is the amount of forwarded over certain time interval.

Channel Efficiency: channel efficiency is a rate at which a network delivers maximum information from source to destination.

Delay: Delay refers to the time taken for a packet to be transmitted across a network from source to destination. Delay, $D = T_d - T_s$ T_d = packet received time at destination T_s = packet time at source.

4.1 Experimental Results

We evaluated the improvements achieved by ANRS, including throughput and channel efficiency, QoS satisfiability, and reduction of ripple effects.

A) Throughput and Channel-Efficiency Gains:

We first study throughput and channel-efficiency gains via ANRS's real-time reconfiguration. We run one UDP flow at a maximum rate over a randomly chosen link in test-bed while increasing the level of interference every 10s.

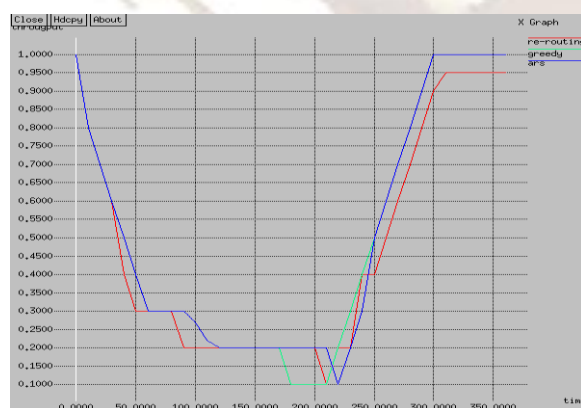


Fig 1: Throughput

We also set the QoS requirement of every link to 6 Mb/s and measure the flow's throughput progression every 10 s during a 400-s run.. Note that we do not intentionally run a greedy algorithm

in this single-hop scenario because its effect is subsumed by ANRS.

ANRS effectively reconfigures the network on detection of a failure, achieving 450% and 25.6% more bandwidth than static-assignment and local re-routing, respectively. ANRS accurately detects a link's QoS-failure using link-quality monitoring information, and completes network reconfiguration (i.e., channel switching) within 15 seconds on average, while the static-assignment experiences severe throughput degradation. Note that the 15-second delay is due mainly to link-quality information update and communication delay with a gateway, and the delay can be adjusted. Further, within the delay, actual channel switch delay is less than 3 ms, which causes negligible flow disruption. On the other hand, the local re-routing improves the throughput by using a detour path, but still suffers from throughput degradation because of an increased loss rate along its detour path.

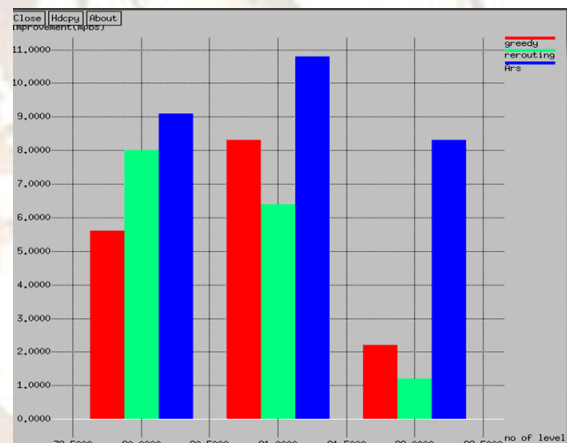


Fig 2: Improvement in throughput

ANRS also improves channel efficiency (i.e., the ratio of the number of successfully delivered data packets to the number of total MAC frame transmissions) by more than 90% over the other recovery methods. Using the data collected during the previous experiment, we derive channel efficiency of the UDP flow by counting the number of total MAC frame transmissions and the number of successful transmissions.

ANRS reconfigures a wireless mesh network to meet different QoS requirements. Before each reconfiguration, the gray areas can only accept 1 to 9 UDP flows. On the other hand, after reconfiguration, the network in the areas can admit 4 to 15 additional flows, improving the average network capacity of the gray areas by 3.5 times.. Further, within the delay, actual channel switch delay is less than 3 ms, which causes negligible flow disruption. On the other hand, the local re-routing improves the throughput by using a detour path, but still suffers from throughput

degradation because of an increased loss rate along its detour path.

ANRS improves channel efficiency by up to 91.5% over the local rerouting scheme thanks to its online channel reconfiguration. On the other hand, using static channel assignment suffers poor channel utilization due to frame retransmissions on the faulty channel. Similarly, the local rerouting often makes traffic routed over longer or low link-quality paths, thus consuming more channel resources than ANRS.

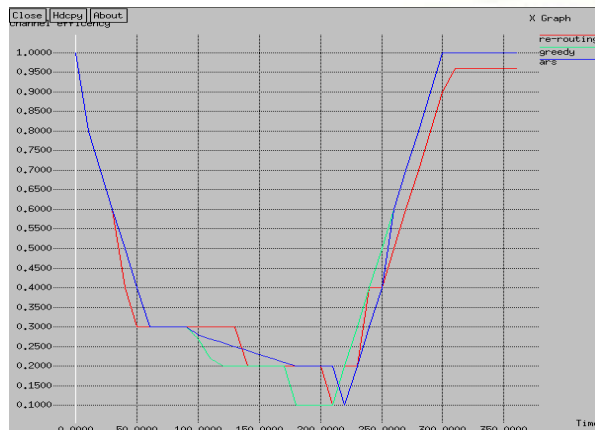


Fig 3: Channel-efficiency gains

Effectiveness of QoS-aware planning: We measured the effectiveness of ARS in meeting the varying QoS requirements in a mr-WMN. We initially assign symmetric link capacity as shown in the channel assignment of the grid topology. Then, while changing the QoS constraints in gray areas at different times (i.e., T1 to T5), we evaluate the improvement of available capacity that ANRS can generate via reconfiguration.

Impact of the benefit function: We also studied the impact of the benefit function on the ARS's planning algorithm. We conducted the same experiment as the previous one with different values of δ in the benefit function. ANRS allows to keep local channel-efficiency high. By contrast, a low value (0.4) can deliver more available bandwidth (on average, 1.2 Mbps) than when the high value is used, since ANRS tries to reserve more capacity.

Impact of the reconfiguration range: We evaluated the impact of the reconfiguration range. We used the same experiment settings as the previous one and focused on reconfiguration requests at T(k). As we increase the hop count (k) from a faulty link(s), we measure the capacity improvement achieved by the reconfiguration plans. In addition, we calculate the capacity gain per change as the cost-effectiveness of reconfiguration planning with different k values. Fig. 4 plots the available capacity of the faulty area

after reconfigurations. As shown in the figure, ANRS can improve the available links' capacity by increasing the reconfiguration range. However, its improvement becomes marginal as the range increases. This saturation results mainly from the fixed number of radios of each node.

In other words, the improvement is essentially bounded by the total capacity of physical radios. Furthermore, because reconfiguration plans with a larger range are required to incur more changes in network settings, the bandwidth gain per change significantly degrades (e.g., capacity gain per change at the hop-count of 4 in Fig. 4). We also observed the similar results in other reconfiguration requests (T2,T3,T4), but omitted them for brevity.

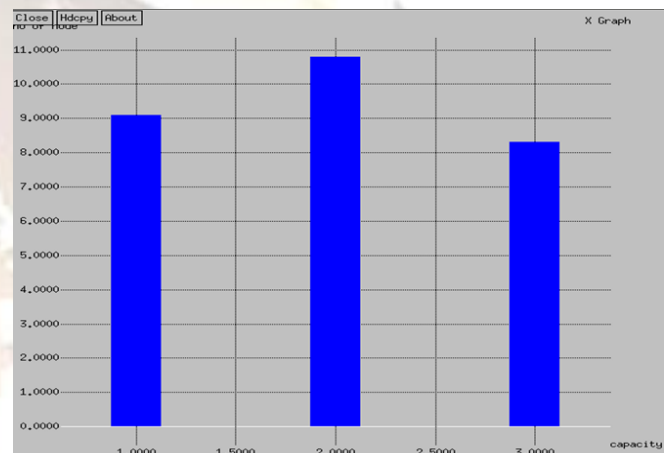


Fig 4: Capacity of nodes in ARS method

B) QoS Satisfaction Gain:

ANRS enhances the chance to meet the varying QoS demands. We use static WCETT routing metric that finds a path with diverse channels and ARS for reconfiguration.

QoS-aware reconfiguration planning in ANRS improves the chance for a WMN to meet the varying QoS demands, on average, by 200%. ANRS effectively discovers and use idle channel through reconfiguration, thus satisfying QoS demands by up to three times more than static-assignment algorithm.

C) Avoidance of Ripple Effects:

We also studied ANRS's effectiveness in avoiding the ripple effects of network reconfiguration. Here three failure recovery methods have been used (i.e., local rerouting, greedy, and ANRS). Since ANRS considers the effects of local changes on neighboring nodes via, it effectively identifies reconfiguration plans that avoid the ripple effects. Under ANRS, the network performs reconfiguration and recovers an average 98% of the degraded throughput (4.8 Mb/s).

5. CONCLUSION

This paper presented an autonomous network reconfiguration system (ANRS) that enables a multiradio WMN to autonomously recover from wireless link failures. ANRS generates an effective reconfiguration plan that requires only local network configuration changes by exploiting channel, radio, and path diversity. Furthermore, ANRS effectively identifies reconfiguration plans that satisfy applications' QoS constraints, admitting up to two times more flows than static assignment, through QoS aware planning. In multihop wireless networks equipped with a CSMA-like MAC, each link's achievable bandwidth (or throughput) can be affected by both link capacity and activities of other links. ANRS identifies feasible changes that help avoid a local link failure but maintain existing network connectivity as much as possible. It can improve the available links' capacity by increasing the reconfiguration range. ANRS's local reconfiguration improves network throughput and channel efficiency. Our experimental evaluations on a Linux-based implementation and ns2-based simulation have demonstrated the effectiveness of ANRS in recovering from local link-failures and in satisfying applications' diverse QoS demands.

References

- [1] I. Akyildiz, X. Wang, and W. Wang, "Wireless mesh networks: A survey," *Comput. Netw.*, vol. 47, no. 4, pp. 445–487, Mar. 2005.
- [2] P. Kyasanur and N. Vaidya, "Capacity of multi-channel wireless networks: Impact of number of channels and interfaces," in *Proc. ACM MobiCom*, Cologne, Germany, Aug. 2005.
- [3] K. Ramachandran, E. Belding-Royer, and M. Buddhikot, "Interference-aware channel assignment in multi-radio wireless mesh networks," in *Proc. IEEE INFOCOM*, Barcelona, Spain, Apr. 2006, pp. 1–12.
- [4] R. Draves, J. Padhye, and B. Zill, "Routing in multi-radio, multi-hop wireless mesh networks," in *Proc. ACM MobiCom*, Philadelphia, PA, Sep. 2004, pp. 114–128.
- [5] D. Aguayo et al., "Link-level measurements from an 802.11b mesh network," in *Proc. ACM SIGCOMM* 2004, Aug. 2004.
- [6] A. Willsky, "A Survey of Design Methods for Failure Detection in Dynamic Systems," *Automatica*, vol. 12, pp. 601–611, 1976.
- [7] A. Brzezinski, G. Zussman, and E. Modiano, "Enabling distributed throughput maximization in wireless mesh networks: A partitioning approach," in *Proc. ACM MobiCom*, Los Angeles, CA, Sep. 2006, pp.26–37.
- [8] D. S. D. Couto, D. Aguayo, J. Bicket, and R. Morris, "A high-throughput path metric for multi-hop wireless routing," in *Proc. ACM MobiCom*, San Diego, CA, Sep. 2003, pp. 134–146.