An Analysis of Reconfiguration Approaches for Recovery in Wireless Mesh Networks

G. Murugaboopathi
Head Of Research & Development
Vel Tech Multi Tech Dr.Rangarajan Dr.Sakunthala Engineering College
Chennai-62, Tamil Nadu, India

T.K.S.Rathishbabu
Assistant Professor
Dept Of Cse
Vel Tech Multi Tech Dr.Rangarajan Dr.Sakunthala Engineering College
Chennai-62, Tamil Nadu, India

R.Venkatesh
Assistant Professor, Dept Of Cse, Velammal Engineering College
Chennai, Tamil Nadu, India

ABSTRACT
Wireless Mesh Network (WMN) is one of the essential elements in the networks of the future because of its ability to provide high bandwidth wireless backbone covering a large physical region. Generally single radio mesh nodes operating on a single channel suffer from capacity issues and hence it is essential to equip mesh routers with multiple radios using multiple non overlapping channels. But during their lifetime, multi radio wireless mesh networks suffer from link failures caused by channel interference, dynamic obstacles, and applications bandwidth demands. This paper presents a detailed analysis of various reconfiguration techniques used to recover wireless mesh network from link failures and the issues to be addressed in order to maximize the network performance. Reconfiguration schemes make use of primitive link changes such as channel, radio and route switch operations to recover WMNs from link failures. In general, reconfiguration schemes generate a set of reconfiguration plans and select the best plan according to the optimality criteria defined specific to that particular scheme. The system cooperatively reconfigures network settings among all mesh routers based on this best reconfiguration plan and thus recover from link failure.

Index Terms
Wireless mesh networks, reconfiguration approach, wireless link failure, recovery, performance improvement.

1.INTRODUCTION
Wireless Mesh Network is a promising wireless technology for numerous applications such as broadband home networking, community and neighborhood networks, enterprise networking, building automation, etc [2]. It is gaining significant attention as a possible way for internet service providers, carriers and others to roll out robust and reliable wireless broadband service that needs minimal investments. With the capability of self organization and self configuration, WMNs can be deployed incrementally, one node at a time, as needed. As more nodes are installed, the reliability and connectivity for the users increase accordingly.

In WMNs, nodes are comprised of mesh routers and mesh clients. Each node operates not only as a host but also as a router, forwarding packets on behalf of other nodes that may not be within direct wireless transmission range of their destinations. A WMN is dynamically self organized and self configured, with the nodes in the network automatically establishing and maintaining mesh connectivity among themselves creating, in effect, an ad hoc network [14]. This feature brings many advantages to WMNs such as low upfront cost, easy network maintenance, robustness, and reliable service coverage. Figure 1 shows the architecture of a wireless mesh network consisting mesh routers and mesh clients such as laptops and mobile phones.

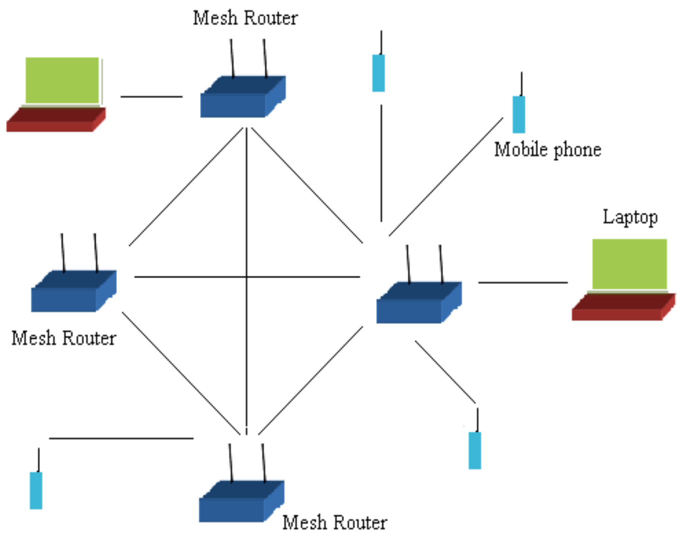

Fig.1. Wireless Mesh Network

Other than the basic routing capabilities of a conventional wireless router, a wireless mesh router contains additional routing functions to support mesh networking. To further improve the flexibility of mesh networking, a mesh router is usually equipped with multiple wireless interfaces built on either the same or different wireless access technologies. Compared with a conventional wireless router, a wireless mesh router can achieve the same coverage with much lower transmission power through multi-hop communications. Optionally, MAC protocol in a mesh router is enhanced with better scalability in a multi hop mesh environment. Wireless mesh networks have gained strong popularity in the modern world. The usage of WMNs is increasing day by day. Common applications of WMNs are seen in sectors such as health care, retail, manufacturing, warehousing and academia. These industries have profited from the productivity gains of using hand held terminals and notebook computers.

2.MOTIVATION

Here we describe the need for reconfiguration system in wireless mesh networks. During their operating period, WMNs encounter link failures frequently. The reasons for such link failure can be channel interference, huge obstacles and bandwidth requirements of the application. 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 such as a hospital or police station might not be able to use some frequency channels because of spectrum etiquette or regulation. Maintaining the performance of WMNs in the face of dynamic link failures remains a challenging problem. Because of these failures, performance of WMNs is affected severely. To recover from such problems manual network management system can be deployed. But it is too expensive. Hence it is essential to make use of a reconfiguration system and the proposed ERS may be deployed in such situation to preserve the network performance.

a.Recovering from poor link quality

The quality of wireless links in WMNs can degrade due to severe interference from other co-located wireless networks [1], [13]. 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. One solution is to employ a channel switch where, by switching the tuned channel of a link to other interference free channels, local links can recover from such a link failure.

b.Providing required QoS

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

c.Handling channel unavailability

Links in some areas may not be able to access wireless channels during a certain time period due to spectrum etiquette or regulation [5], [8]. For example, some links in a WMN need to vacate current channels if channels are being used for emergency response such as hospital or public safety. Such links can seek and identify alternative channels available in the same area.

3. RELATED WORK

The summary of various techniques employed in recovering WMNs from link failures and maximizing the performance is presented in this section. Though there are several techniques used, this section mainly focuses on four schemes namely Autonomous Reconfiguration System, interference aware channel assignment, greedy channel assignment and initial resource allocation method. An overview of basic idea of each and every technique, their advantages and the associated challenges are given below.

a.Autonomous Reconfiguration System (ARS)

Kyu Han Kim et al [7] proposes an autonomous network reconfiguration system that enables a multi radio WMN to autonomously recover from local link failures and to preserve expected performance. Figure 2 depicts the steps followed by ARS to maximize the performance.

Fig.2. ARS Operation

ARS makes use of channel and radio diversities in WMNs. By generating necessary changes in local radio and channel assignments it enables network to recover from failures. Based on the thus generated configuration changes, the system cooperatively reconfigures the overall network settings. Experimental evaluation shows that ARS outperforms existing failure recovery schemes in improving channel efficiency by more than ninety percentage. The most important limitation of this approach is that it only considers channel related failures and does not deal with node failures. Further it does not consider the reconfiguration cost while selecting the best plan and thus it is not a cost aware reconfiguration technique.

b.Greedy Channel Assignment

Greedy channel assignment algorithms can reduce the requirement of global network changes by changing settings of only the faulty links. Ashish Raniwala et al [10] considers novel multi channel WMN architecture, specially tailored to multi hop wireless access network applications. Their method makes use of fully distributed channel assignment algorithm that can adapt to traffic loads dynamically. It employs a load balancing algorithm which can adapt to traffic load changes as well as network failures automatically. The greedy approach suffers from the ripple effect, in which one local change triggers the change of additional network settings. But the strength of a reconfiguration scheme depends on its ability to make the changes as local as possible. Only by considering configurations of neighboring mesh routers in addition to the faulty link, better performance could be achieved.

c.Interference Aware Channel Assignment(IACA)

Ramachandran et al [9] proposes an interference aware channel assignment method and protocol for multi radio wireless mesh networks that addresses interference problem. Their system intelligently assigns channels to radios providing minimal interference within the mesh network and between the mesh networks and co-located wireless networks. It deploys a novel interference estimation technique that can be implemented at each mesh router. The basis for the method is the idea of multi radio conflict graph which is an extension to the conflict graph, used to model the interference between the routers. This scheme shows performance gain in excess of forty percentage compared to static channel assignment techniques. The major issue associated with this approach is that it can only improve overall network capacity by using additional channels. It does not take into account together both the essential aspects namely link association and local traffic information.

d.Initial Resource Allocation Techniques

Alicherry et al [3] describes about the joint channel assignment techniques. In his work, joint channel assignment and routing problem is mathematically formulated taking into account the interference constraints, the number of channels in the network and the number of radios available at each mesh router. The mathematical formulation is used to derive a solution which optimizes the overall network throughput subject to fairness constraints Experimental evaluation demonstrates that the proposed algorithm can effectively exploit the increased number of channels and radios, and it performs much better than the theoretical bounds.

Brzezinski, et al [4] proposes a partitioning technique for maximizing throughput. His method takes advantage of the inherent multi radio capability of WMNs. The partitioning approach that is employed is based on the notion of local pooling. Using this notion, several topologies are characterized in which high throughput can be achieved in a distributed fashion. The algorithm partitions the network in a manner such that high capacity regions are identified. The performance evaluations show that they significantly increase the usable capacity region. The resource allocation algorithms can provide theoretical guidelines for initial network resource planning. Though the approaches described above provide a comprehensive and optimal network configuration plan, they often require global configuration changes. But for a reconfiguration scheme to be robust and effective, it is essential to avoid global reconfiguration. In general making configuration changes globally is undesirable in case of frequent local link failures.

4. ERS ARCHITECTURE

In this section, we first present an overview of the Enhanced Reconfiguration System followed by the overall architecture and the description of each and every component.

a. Overview

ERS is a system that is easily deployed in multi radio wireless mesh network. Running in every mesh node, ERS supports self reconfigurability by providing the features such as localized reconfiguration, QoS aware planning, link quality monitoring and cross layer interaction. Based on multiple channels and radio associations available, ERS generates reconfiguration plans that allow for changes of network configurations only in the vicinity where link failures occurred while retaining configurations in areas remote from failure locations. Also ERS accurately monitors the quality of links of each node in a distributed manner and effectively identifies QoS satisfiable reconfiguration plans. Furthermore, based on the measurements and given links' QoS constraints, ERS detects local link failures and finally initiates network reconfiguration.

b. System Architecture

In ERS, the reconfiguration plan generation and selection process takes place in the gateway. Every mesh node monitors the quality of its outgoing wireless links periodically and reports the results to a gateway. Once it detects a link failure, the gateway synchronizes and generates a reconfiguration plan for the request. The gateway sends the reconfiguration plan to the nodes. Finally, all nodes in the group execute the corresponding configuration changes. ERS systematically generates reconfiguration plans that localize network changes by dividing the reconfiguration planning into four processes i.e. feasible plan generation, QoS test, cost analysis and optimal plan selection. The components of the Enhanced Reconfiguration System are shown in figure 3.

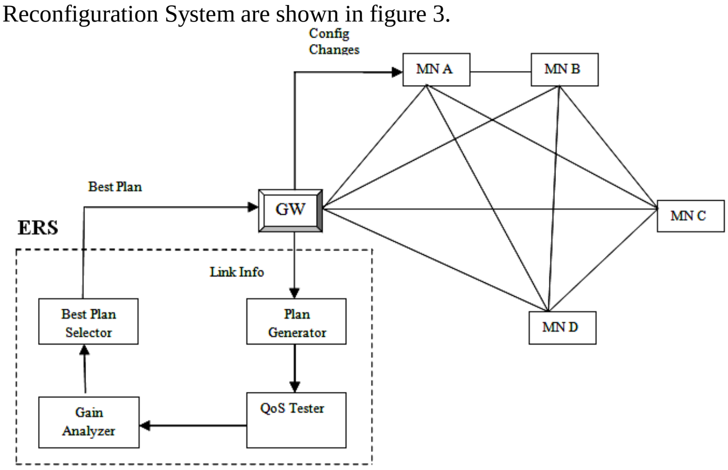

Fig.3.Components of ERS

ERS first applies connectivity constraints to generate a set of feasible reconfiguration plans (FP) that enumerate feasible channel, link, and route changes around the faulty areas, given connectivity and link failure constraints. Then, within the set, ERS applies strict constraints such as QoS and network utilization to identify a reconfiguration plan that satisfies the QoS demands (SP) and that improves network utilization most. Cost analyzer computes the total reconfiguration cost associated with each and every plan generated. Finally optimal plan selection component selects the best plan from among the set of reconfiguration plans. The configuration changes are made at all the mesh nodes based on this plan.

1.*Plan Generation Subsystem*

Given multiple radios, channels, and routes, ERS identifies feasible changes that help avoid a local link failure but maintain existing network connectivity as much as possible. ERS 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, ERS uses a k-hop reconfiguration parameter. Figure 4 depicts the operation of feasible plan generation component.

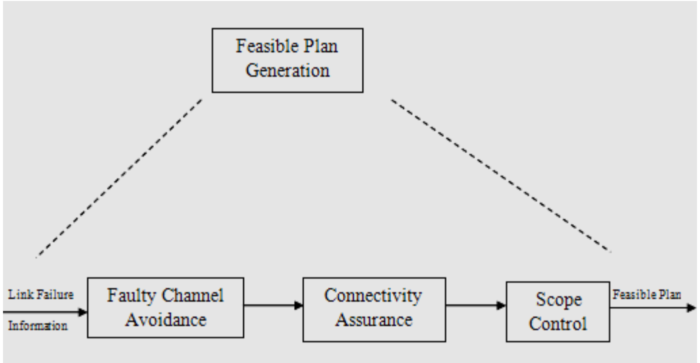

Fig.4. Feasible Plan Generator

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, ERS identifies feasible changes and lists out all possible reconfiguration plans to recover from failure. However, in generating such plans, ERS has to address the following challenges.

• *Faulty Channel Avoidance*: ERS has to ensure that the faulty links are fixed using reconfiguration. To achieve this ERS makes use of three primitive link changes namely channel switch, radio switch and route switch. A channel switch is a reconfiguration primitive where both end radios of link can simultaneously change their tuned channel. A radio switch is another primitive where one radio in one node can switch its channel and associate with another radio in another node. A route switch is a technique where all traffic over the faulty link can use a detour path instead of the faulty link.

• *Connectivity Assurance:* It is essential that ERS maintains connectivity with the full utilization of radio resources. It is very important that ERS maximizes the usage of network resources. This is achieved by making each radio of a mesh node associate itself with at least one link and by avoiding the use of same channel among radios in one node.

• *Scope Control*: ERS has to limit network changes as local as possible and for this it uses a k hop reconfiguration parameter. Starting from a faulty link, ERS considers link changes within the first k hops and generates feasible plans. If it cannot find a local solution, it increases the number of hops so that it may explore a broad range of link changes.

2.*QoS Examination*

For each feasible plan, ERS has to check whether each link's configuration change satisfies its bandwidth requirement, so it must estimate link bandwidth. To estimate link bandwidth, ERS accurately measures each link's capacity and its available channel airtime [11]. ERS estimates an individual link's capacity based on measured link quality information [12] and data transmission rate measured by passively monitoring the transmissions. Besides the link change, ERS needs to check whether neighbouring links are affected. To identify such adverse effect from a plan, ERS 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. Otherwise, the effects of local changes will propagate, causing cascaded QoS failures. Figure 5 depicts the architecture of the QoS Test subsystem.

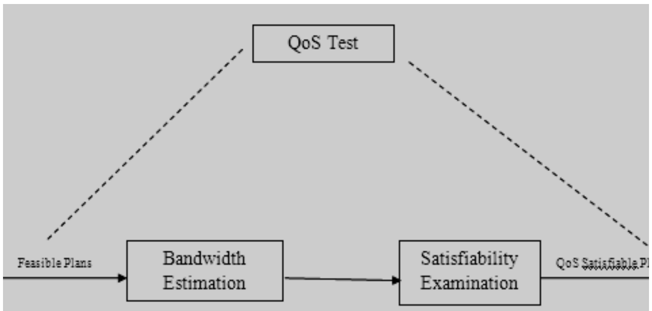

Fig.5. QoS Test Subsystem

ERS 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.

3.*Optimal Plan Selection*

ERS now has a set of reconfiguration plans with the reconfiguration cost of each computed. It has to choose a plan within the set based on the cost criterion. The best plan is one which maximizes the utilization as well as throughput and minimizes the total reconfiguration cost. All plans with utilization greater than user defined limit δ are identified and the one with minimum reconfiguration cost is selected as the best plan. Now the reconfiguration changes mentioned in this plan has to be executed by all the nodes.

5. SYSTEM EXPERIMENTATION

The following section deals with the model that describes the working of ERS and the expected results are presented. We assume that the reconfiguration scheme involves changes to the configuration upto a maximum of three hops from the failed node. The value of α, β and γ is set to 5, 7 and 10 respectively. Let the limit δ be set to 50.

TABLE I
CONFIGURATION COST AFTER APPLYING FILTER

No	CS	RS	DP	NC	UP
6	1	0	1	2	81
8	2	1	0	3	82
13	0	1	2	3	96
14	3	0	0	3	53
16	0	0	3	3	84

a.Best Plan Selection

For each feasible plan, ERS has to check if it satisfies the expected utilization δ. The result after this test is shown in table I, which consists of all reconfiguration plans with UP greater than user defined threshold. Here we compare the working of ARS and ERS. For the plans specified in the table I, ARS algorithm would select the plan 13 as the best plan as it maximizes UP. But the ERS scheme computes the special parameter η. The value of η may be computed using the formula given below.

$$\eta_i = UP_i / C_i$$

From the set of plans, ERS selects the plan which maximizes the value of η as the best plan. For the above mentioned example ERS would choose plan that maximizes η as the best reconfiguration scheme.

b.Inferences

For each and every plan in table I the cost and corresponding UP can be visualized. Figure 6 shows the graph containing plans along x axis and their corresponding UP and configuration cost along y axis. The plan that maximizes the utilization and minimizes the total reconfiguration cost is considered to be the best.

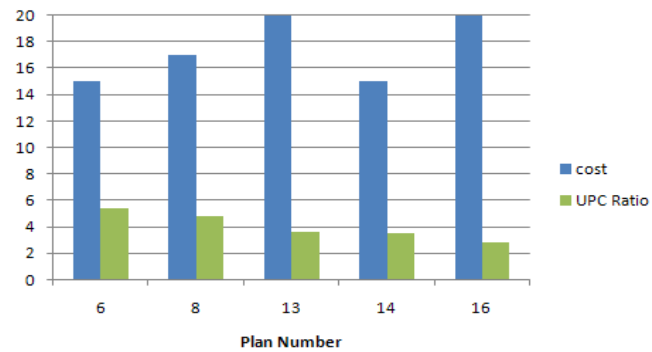

Fig.6. UP versus Reconfiguration cost

6.CONCLUSION

This paper first presents a detailed analysis on the work done in the past to recover WMNs from link failures. One of the existing techniques called ARS proposes an autonomous, QoS aware reconfiguration system. But the idea of cost aware reconfiguration is not effective in this scheme. An effective reconfiguration scheme is the one which completely exploits the property of localized reconfiguration and cost efficiency along with the objective of maximizing channel utilization. Thus with this idea, an enhanced reconfiguration system ERS is proposed. In general, goal of the any reconfiguration scheme would be to recover from network failures as a best effort service. But the enhanced reconfiguration system further refines the process of the selecting the best reconfiguration plan by introducing the idea of cost effectiveness along with the objective of maximizing the throughput and utilization of the channel. Because ERS includes a link association primitive, it can learn available channel capacity by associating with idle interfaces of neighbouring nodes. This aspect could be verified experimentally. Several QoS parameters can be taken into consideration and corresponding results can be observed. It is also essential to consider other types of system failures in addition to link failure and even such situations should be handled during the recovery process. Another direction of experimentation is to analyze the performance by jointly considering the flow assignment and reconfiguration problem.

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