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RESEARCH ARTICLE

FEASIBILITY BASED RECONFIGURATION APPROACH FOR RECOVERY IN WIRELESS MESH NETWORKS

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ABSTRACT

Wireless Mesh Network (WMN) is one of the important elements in the future networks as it has the ability to provide high bandwidth wireless backbone which covers a wide physical region. In general single radio mesh nodes operates on a single channel and it suffers from capacity concern. Hence it is necessary to provide mesh routers with multiple radios using multiple non overlapping channels. But, multi radio WMN suffer from link failures caused by interference of the channel, dynamic obstacles, and applications bandwidth demands during their lifetime. In this paper exhaustive analysis of various reconfiguration techniques is presented which is used to recover wireless mesh network from link failures and the issues to be addressed in order to maximize the network performance. A reconfiguration scheme utilizes primitive link changes such as channel, route switch operations and radio to recover WMNs from link failures. Generally, reconfiguration schemes produce a set of reconfiguration plans and opt for the best plan according to the desired criteria which is required for that particular. Based on this best reconfiguration plan the system reconfigures network settings among all mesh routers and thus make progress from link failure.

Index Terms

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

INTRODUCTION

Wireless Mesh Network shows potential in wireless technology for various applications such as community, broadband home networking and neighborhood networks, etc [2]. It is serves as a possible way for internet service providers, carriers and others to compress robust and reliable wireless broadband service that needs negligible reserves. Because of self organization and self configuration capability, WMNs can be deployed incrementally, one node at a time, as required. As more number of nodes is installed, the users reliability and connectivity increases.

In WMNs, nodes consist of mesh clients and mesh routers. Each node not only operates as a host but also as a router, which forwards packet on behalf of other nodes that doesn't exist in direct wireless transmission range of their destinations. A WMN is self organized and configured, with the nodes in the network which automatically establish and maintain a mesh connectivity among themselves creating, in effect, an ad hoc network [14]. This quality brings many advantages to WMNs such as low upfront cost, robustness, easy network maintenance and reliable service coverage. The architecture of a wireless mesh network consisting mesh routers and mesh clients which includes laptops and mobile phones are shows in the fig 1.

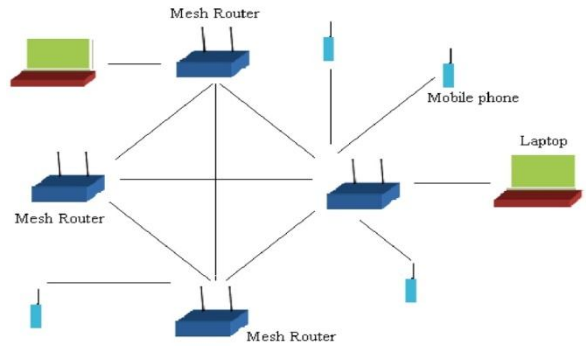

Fig.1 Wireless Mesh Network (WSN)

Apart from basic routing capabilities of a conventional wireless router, a wireless mesh router has additional routing functions in order to support mesh networking. For the further improvement of the flexibility of mesh networking, a mesh router is usually prepared with multiple wireless interfaces built on either the same or the different wireless access technologies. In comparison with a conventional wireless router, a wireless mesh router through multi-hop communications can achieve the same coverage with much lower transmission power. On the other hand, MAC protocol in a mesh router is enhanced with better scalability in a multi

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hop mesh environment. In the modern world Wireless mesh networks have gained strong popularity. The WMNs usage increases day by day. The most common applications of WMNs are seen in areas such as health care, retail, warehousing, academia and manufacturing. These industries have profited from the productivity gains of using hand held terminals and notebook computers.

MOTIVATION

Here the need for reconfiguration system in wireless mesh networks is described. WMNs encounter link failures repeatedly during their operating period. The reasons for such link failure can be channel interference, bandwidth requirements of the application and huge obstacles. For example, some links of a WMN may encounter significant channel interference from their coexisting wireless networks. Some of the network parts might not be able to meet the increasing bandwidth demands from new mobile users and its applications. Because of spectrum etiquette or regulation some frequency channels may not be used by the Links in a certain area such as a hospital or police station. To maintain the performance of WMNs in the face of dynamic link failures remains a challenging issue. The performance of WMNs is affected severely due to these failures. To overcome such problems manual network management system can be deployed. But it is expensive. Hence it is important to make use of a reconfiguration system and the proposed ERS may be deployed in such situation for preserving the performance of the network.

Recovering from poor link quality

In WMNs the quality of wireless links can degrade due to severe interference from other co-located wireless networks [1], [13]. For instance, Bluetooth, cordless phones, and other coexisting wireless networks which operate on the same or adjacent channels produce considerable and varying degrees of collisions or losses in packet transmissions. The local links can recover from such a link failure by employing a channel switch and to switch the tuned channel of a link to other interference free channels.

Providing required QoS

Increasing QoS demands from end users cannot be accommodated by the links in some areas, depending upon the spatial or temporal locality. For example, during the session links around a conference room may have to relay too much data and video traffic. Similarly relay links outside the room may not support all voice over IP calls during a session break. By re associating their radios or channels with available nearby underutilized radios or channels, communication failures can be avoided.

Handling channel unavailability

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

Related Work

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

Autonomous Reconfiguration System (ARS)

An autonomous network reconfiguration system that enables a multi radio WMN to autonomously recover from local link failures and to preserve expected performance has been proposed by Kyu Han Kim et al [7]. The step followed by ARS to maximize the performance is shown in Figure 2.

Fig.2 ARS Operation

ARS makes use of channel and radio diversities. It enables network to recover from failures by generating necessary changes in local radio and channel assignments. On the basis of those generated configuration changes, the system cooperatively reconfigures the overall network settings.ARS outperforms existing failure recovery schemes in improving channel efficiency by more than ninety percentage is shown by an Experimental evaluation. The most important limitation of this approach is that it only considers channel related failures and does not include node failures. Also it does not consider the reconfiguration cost while selecting the best plan and hence it is not a cost aware reconfiguration technique.

Greedy Channel Assignment (GCA)

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.

Interference Aware Channel Assignment (IACA)

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

Initial Resource Allocation Techniques (IRA)

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

To maximize the throughput Brzezinski, et al [4] proposes a partitioning technique. This method makes use of the advantage of the WMNs inherent multi radio capability. The partitioning approach is based on the notion of local pooling. By using this notion, several topologies in a distributed fashion are characterized in which high throughput can be achieved. The algorithm partitions the network in such a way that high capacity regions are identified. The performance evaluation shows that the usable capacity region is increased significantly. For initial network resource planning the resource allocation algorithms can provide theoretical guidelines.In spite of comprehensive and optimal network configuration plan, these approaches often require global configuration changes. But to make a reconfiguration scheme to be robust and effective, it is essential to avoid global reconfiguration. In case of frequent local link failures making configuration changes globally is undesirable.

ERS ARCHITECTURE

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

Overview

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

System Architecture

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

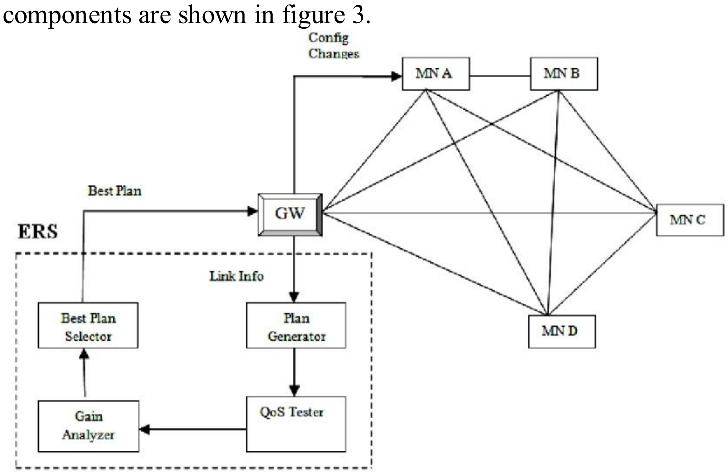

Fig.3 Components of ERS

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

Plan Generation Subsystem

ERS identifies feasible changes that help to avoid a local link failure with the given multiple radios, channels, and routes but maintains existing network connectivity as much as possible. Also it has to limit network changes as local as possible, but at the same time it requires to find a locally optimal solution by considering more network changes or scope in account. To obtain this tradeoff, ERS uses a k-hop reconfiguration parameter. Figure 4 depicts the operation of feasible plan generation component.

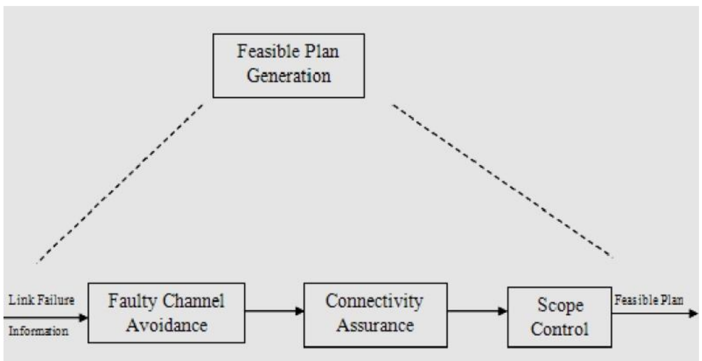

Fig.4 Feasible Plan Generator

Feasible plans generation is essential to search all legitimate changes in links' configurations and its combinations around the faulty area. With the available multiple radios, channels, and routes, ERS identify feasible changes and to recover from failure it lists out all possible reconfiguration plans. However, generating such plans makes ERS to address the following challenges.

***Faulty Channel Avoidance*:** ERS must ensure that the faulty links are fixed using reconfiguration. To obtain this ERS makes use of three primitive link changes namely channel switch, radio and route switch. A channel switch is a reconfiguration primitive where both end radios of the link can simultaneously change their tuned channel. A radio switch is another primitive where one radio in one node can switch its channel and connect 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 necessary that ERS maintains connectivity with the full utilization of radio resources. Also it is very important that ERS maximizes the usage of network resources. This can be 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 limits network changes as local as possible and for this it uses a k hop reconfiguration parameter. Starting from a faulty link, it considers link changes within the first k hops and generates feasible plans. If a local solution is not found, it increases the number of hops so that it may explore a broad range of link changes.

QoS Examination

For each feasible plan, it is essential that ERS checks whether each link's configuration change satisfies its bandwidth requirement, so it must estimate link bandwidth. In order to estimate link bandwidth, ERS accurately measures each link's capacity and its available channel airtime [11]. Also ERS estimates an individual link's capacity based on measured link quality information [12] and data transmission rate is measured by passively monitoring the transmissions. ERS needs to check whether neighboring links are affected. To make out 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. If not, the effects of local changes will propagate, causing cascaded QoS failures. Figure 5 depicts the architecture of the QoS Test subsystem.

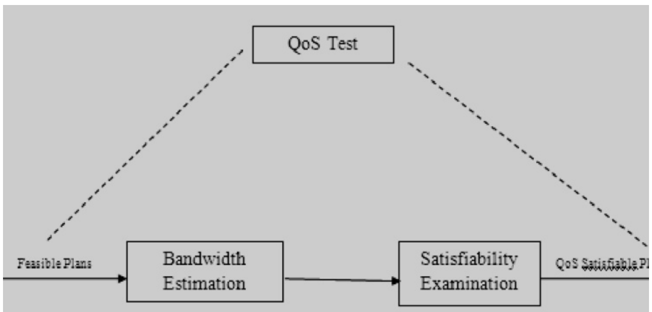

Fig.5 QoS Test Subsystem

ERS now contains a set of reconfiguration plans that are QoS satisfiable and desires to choose a plan within the set for a local network to have evenly distributed link capacity.

Optimal Plan Selection

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

System experimentation

This section deals with the model that describes the working of ERS and the expected results are presented. Let us 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

Best Plan Selection

For each feasible plan, ERS has to check whether it satisfies the expected utilization δ or not. The result after this test is shown in tableI, which consists of all reconfiguration plans with UP greater than user defined threshold. 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. However 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 set of plans, ERS selects the plan which maximizes the value of η as the best plan. For the above described example ERS would choose plan that maximizes η as the best reconfiguration scheme.

Inferences

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

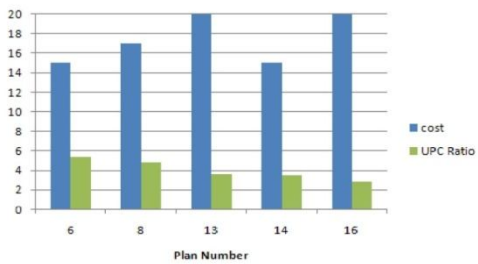

Fig.6 UP versus Reconfiguration cost

CONCLUSION

This paper presents a detailed analysis on the work done in the past to recover WMNs from link failures. An existing technique called ARS proposes an autonomous, QoS aware reconfiguration system. However 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, an enhanced reconfiguration system ERS is proposed. The 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 also utilization of the channel. Since ERS includes a link association primitive, it learns available channel capacity by associating with idle interfaces of neighboring nodes. This feature could be verified experimentally. Numerous 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 such situations should be handled during the recovery process. Another way of experimentation is to analyze the performance by jointly considering the flow assignment and reconfiguration problem.

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