Managing Wireless Mesh Networks – A Survey of Recent Fault Recovery Approaches

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Abstract. Wireless Mesh Network (WMN) is a technology which has evolved in recent years and fits well in today's technological needs. However, due to the wireless nature of WMNs and their deployment in heterogeneous and large scale areas, wireless links often face significant quality fluctuations and performance degradation or weak connectivity. Therefore, failure detection and recovery plays crucial role in performance of WMN. This paper presents a study report on comparison of recent research and techniques developed for the issue of fault tolerance in WMNs. In this survey we present the existing techniques for fault tolerance in WMNs in categories; node failure approach, communication failure approach, routing schemes, fault tolerance techniques, and autonomous reconfiguration systems. The paper also provides an outline of areas which need further research and studies.

Keywords: Wireless mesh network · Fault tolerance · Cross-layer

1 Introduction

Wireless Mesh Network (WMN) is a specific type of Mobile Ad Hoc Networks (MANET) [12], which extends the concept of single-hop WLANs to a multihop network. In WMNs, nodes can automatically join or leave the network and networks can be established instantly virtually anywhere. WMNs' advantages such as low up-front cost, self-managing, robustness, and reliable service coverage encourage researchers to study their features for better and more reliable performance [2].

The main intention of WMNs is the capability of working without infrastructure. This feature and the inherit features of a wireless connectivity, such as interference, limited bandwidth, packet loss, dynamic obstacles, and fading makes WMNs not stable and reliable in all situations [6]. They may experience various failures, for example, node or link failures which may result in service interruption and degrading the performance of WMNs [8].

Hence, it is crucial to find the solutions necessary for WMN fault detection and recovery in order to make them fault tolerant. Fault tolerant function optimizes the capability of the network to deliver the data constantly and successfully during the specific time when some node or link failures happen.

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The concept of Situation detection [16] can be used for developing a fault tolerance mechanism for WMNs. Considerable amount of event data due to changes in WMNs are produced that need to be analyzed. Gaining spatio-temporal information about the occurrence of faults enriches fault recovery mechanism. Based on the spatio-temporal data about faults, root cause and type of faults can be diagonized. Detecting faults in WMNs in time to take appropriate actions for obtaining desired QoS and save network resources can enhance WMNs performance.

Designing reliable and fault tolerant WMNs have been a hot topic of research of wireless networks during the last decade and many studies and research have been undertaken to address issues in WMNs to make them more dependable.

In this paper we present and compare the recent approaches and techniques developed for making WMNs fault tolerant against node failure, communication failure, routing protocol failure, backbone and base station failures.

2 Faults in WMNs

Based on our study, there are a number of faults that can happen in WMNs and effect the performance of the network severely. We have distinguished WMN faults in the following categories.

2.1 Node Failure

Failure in Mesh nodes occur in different ways, such as hardware failure or software issues. Node failure decreases the performance level of WMNs. More reasons which cause node failure are, deficiency in WMN coverage domain, nodes weariness after operating in a network for a long time, interruption in routing path, or reduction in node battery power [15].

2.2 Communication Failure

The wireless nature of WMNs cause their links facing quality fluctuations and performance degradation by experiencing various issues such as interference, limited bandwidth, unpredictable circumference, multi-path fading, weak signal, dynamic obstacles [10], channel overlapping and reconfiguration overhead caused by channel switching in multi channel-multi radio WMNs [5].

2.3 Traffic Overload

The other important connectivity issue is the traffic congestion (overhead). From one hand the dynamic nature of traffic demand in WMNs and also excessive throughput requested by some applications and from the other hand the limited bandwidth capacity of WMNs can cause significant traffic congestion and degrade network performance dramatically. Moreover, network traffic can be interrupted and congestion might happen due to the network structure changes or because of faults happening during the network operations.

2.4 Routing Protocol Failure

The existing routing schemes used for WMN need improvements to satisfy required QoS and to provide optimal performance level for all situations in the network. In some conditions the routing protocol messages in the network are delayed or lost and cause the routing protocol to face problems to continue operation. Moreover, the bandwidth and computing resources of communication is limited for each node, therefore wastage of time, resources, traffic overhead and bandwidth occur due to protocol decision making.

2.5 Network Scalability Issue

In wireless mesh networks the number of nodes continuously changes. The existing routing protocols work best for smaller mesh networks but cannot operate efficiently once the network is large and heterogeneous. As the network enlarges, the number of hops in the network increase, new routes are required to be established and traffic load should be calculated for different network routes. In this new condition routing mechanisms might face difficulty to find appropriate and reliable route, connections in transport protocols may weaken and MAC protocols may experience reduction in throughput. This results in increment of the number of network operations and can degrade the performance of the network [1,6].

2.6 Faults Resulting from Network Dynamics

Due to the dynamic nature of WMNs, the structure and topology of the network might stay unchanged or change often. Moreover, nodes are allowed to stay stationary or become mobile by moving around and change their location. These topological changes require WMNs for reconfiguring and reorganizing the network structure which can add more complexity and overhead.

2.7 Base Station and Backbone Failures

Mesh routers are the base stations and the connectivity among them creates a wireless multi-hop backbone for WMNs [7]. Base station and backbone faults can make network unstable and create confusion for route selection and data flow. Faults related to base station and network backbone are: weak radio frequency signal or unpredictable circumference which effect the QoS in the coverage zone, capture effect by base station with high transmission power, battery wear out, excessive energy consumption, hardware failure, gateway selection when instant changes occurs in the network.

3 Taxonomy of Approaches

This section presents the recent developed techniques for addressing current issues in WMNs. These techniques are organized in the following taxonomy: (a) Fault Diagnosis Approach, (b) Node Failure, (c) Connectivity Issues and Routing Schemes, (d) Fault Tolerance, (e) Autonomous Reconfiguration Systems.

3.1 Fault Diagnosis Approach

Xu et al., developed a fault diagnosis model for WMNs [17]. During the fault diagnosis process a shortest path spanning tree is constructed. Each node included in the tree has the shortest hop-distance to the root. In this way the delay time is reduced. Each node produces a testing request message and broadcast it to its neighbors. The reply message is not needed. Therefore, the overhead of maintaining and repairing the spanning tree is prevented and also communication and time complexity is enhanced significantly.

Li et al., propose a fault diagnosis model based on decision tree algorithm named W-C4.5-RP [9]. The developed model is basically the improvement of the C4.5 decision tree algorithm by adapting rule post-pruning mechanism. The main advantage of the developed fault diagnosis algorithm is reducing the rule set size and cutting down the rule matching time that increases the system efficiency.

3.2 Node Failure Approach

In [15] authors proposed a node recovery algorithm that replaces inactive nodes or the ones which have vacated batteries. Fault Node Recovery (FNR) algorithm allows to reuse maximum number of routing paths. As the result the network lifetime increases and on the other hand cost of node replacement decreases by consuming less power during the route discovery process.

3.3 Connectivity Issues and Routing Schemes

Franklin et al., address the problem of joint channel assignment and flow allocation in WMNs [5]. The research has proposed a static channel assignment algorithm for improving performance of WMNs by using multiple partially overlapped channels. The proposed algorithm is called Mix Integer Linear Program (MILP). The algorithm is considered load aware and deliberates increasing end-to-end throughput and decreasing queuing delay in the network.

In [4] Franklin et al., propose a solution for traffic disruption overhead that happens during channel switching in order to reconfigure the channel assignment in Multi Channel - Multi Radio (MC-MR) WMNs. The paper provides a mathematical model for reconfiguration of the network when channel switching occurs which can minimize traffic disruption and increase the throughput usage.

Papapostolou et al., proposes a simple approach for obtaining fault tolerance in WMNs [11]. Their proposed approach has three main characteristics; it adapts to changes in the network, it avoids traffic to be forwarded by unreliable nodes and selects routing path differently with a joint link metric. Their proposed link metric encapsulates distance between nodes and their inclination and vulnerability to failure. The result of the research shows certain advantages of joint link metric.

3.4 Fault Tolerance Approaches

Aizaz et al., propose a failure recovery method for TICA (Technology-controlled Interference-aware Channel-assignment Algorithm) [3]. When a failure happens the algorithm bypasses the failed node and removes its related MPNT (Maximum Power Neighbor Table). Then gateway executes the TCA (Topology Control Algorithm) to reorganize the network by making a new MPSPT (Minimum Power-based Shortest Path Tree). The new MPSPT helps gateway to recalculate the link rankings and the channel assignment. The result provided in [3] shows TICA performs well in small and large scale networks.

Ivanov et al., proposed a fault-tolerant mechanism for base station planning [7]. The developed algorithm has three steps: optimization step which finds an optimal solution for requirements and needed conditions for last mile and backbone coverage. Connectivity testing step analyzes the resulted graph for bio-connectivity. The consolidation step makes a single vertex by mapping parts of the graph that are bio-connected. In this way the algorithm generates true results after limited number of iteration during acceptable time period.

Wang et al., proposed two routing algorithms based on k-submesh concept [14]. They utilized probabilistic method on the fault tolerance of the developed algorithms. For example if nodes fail independently with given probability the algorithms are able to return a fault-free path. They provided formal proof for their algorithm's performance.

In [13] authors propose a mechanism for WMNs to recover the packets omitted by the source. The proposed mechanism is a fault-tolerant technique based on network coding and integrates the multi-path routing and random linear network coding method by enhancing the traditional coding nodes selection technique. The authors indicate the proposed mechanism has better performance in packet delivery, reducing delay, resource redundancy degree, and useful throughput.

3.5 Autonomous Reconfiguration Systems

Kim et al., propose an autonomous reconfiguration system (ARS) for WMNs in [8]. This mechanism enables a multi-radio WMN to autonomously recover local link failures by reconfiguring its local network settings, radio, and route assignment. The proposed ARS generates reconfiguration plans which satisfy applications' QoS and also needs less changes for the healthy network settings.

In [10] authors presented an Enhanced Reconfiguration System for fault recovery in WMNs. In the proposed approach the gateway is responsible for generating reconfiguration plan and process of choosing the best recovery plan by introducing the idea of cost effectiveness along with the objective of maximizing the throughput. When link failure occurs, the gateway synchronizes and reconfiguration plan is identified according to QoS which improves network utilization.

4 Discussion

The result of our survey shows there is still need for further research in the area of fault tolerance in WMNs. In this section we discuss the areas in WMNs which need further research to address the challenges of enhancing the performance of WMNs and make them fault tolerant.

Cross-Layer Design: The purpose of traditional design of layers in protocol stack is basically encapsulating each layer's information separately and maintaining levels of abstraction so that the implementation of each layer does not interfere with the others. Development of advanced and complex, systems and applications demand more sophisticated techniques to improve the network performance. In WMN there is need to develop protocols that should enable all layers to function interactively to improve quality of services by considering parameters of other layers [2].

There have been efforts to achieve cross-layer design for WMN, but these techniques are partially cross-layer and mostly consider MAC and routing protocol layers. Transport and application layers can be considered in addition to the current partially cross-layer approaches. The application layer determines which part of the missing data is important and what level of loss is tolerable. The transport layer protocols adaptively decide how to re-transmit the data. Such design improves the performance level of WMNs to obtain better QoS. Additionally, it helps the development of smarter fault recovery and self-configuration techniques for WMNs. It is important to consider and prevent the additional overhead that might happen in cross layer approaches. Cross-layer design should not induce unwanted complexity, incompatibility with existing designs and loss of protocol layer abstraction.

Network Dynamics: As WMNs have dynamic and flexible infrastructure, various changes might occur in terms of topological changes, mobility and size of the network either separately or simultaneously which can degrade network performance, cause faults or increase the faults' ratio and types.

Topological Changes: Due to the dynamic nature of WMNs the structure and topology of the network might change often or stay unchanged. Nodes can join and leave the network dynamically making the network unstable and erroneous. This results in frequent variation of connectivity, route failures and energy reduction. Therefore, there is need for adaptive routing protocols, MAC layer and channel assignment schemes, efficient topology control, and power management techniques.

Scalability: As it is discussed in Subsect. 2.4, the scalability issue in WMN is not fully solved yet. Multi-hop protocols face scalability problems when the size of network enlarges which results in network performance degradation. To make WMNs scalable, it is necessary that MAC, routing and transport layer protocols should be made scalable and collaborative. These protocols should not increase network operations exponentially and should minimize overhead and complexity.

Mobility: In order to make WMNs able to enhance mobility, sophisticated physical layer techniques should be developed which adapt to fast hand-offs and fast fading that are correlated to mobile nodes. Moreover, these techniques should be able to handle the shift in frequency, employ low latency handover and location management algorithms to enhance QoS during mobility [6].

Fault Tolerance: As it has been presented in the previous section most of the fault recovery mechanisms in WMNs deal with one type of failure. There is need for more robust approaches which help WMNs to recover from different types and composite faults such as node failure, communication failure, protocol failure, and traffic congestion. The mechanism should be able to prioritize faults in the network and assign the needed resources for recovering the more important failures first.

Most of the recovery techniques consider reliability of data delivery as a metric for performance measurement. In fact, high availability of the radio coverage and timeliness are also important for many applications. For adding these two requirements to the recovery mechanism energy efficiency should be considered and complexity should be prevented.

5 Conclusion

WMNs' advantages such as low up-front cost, self-forming, self-managing, robustness, and reliable service coverage consistently make it a promising technology for the era of mobility.

In contrast, due to the wireless nature of WMNs and their deployment in heterogeneous and large scale areas, wireless links often face various types of failures which results in significant quality fluctuations and performance degradation [7]. Therefore, designing reliable and fault tolerant WMNs have been a hot topic of research of wireless networks during the recent years.

In this paper we presented and compared the approaches and techniques which have been developed for making WMNs fault tolerant. First, we described different types of faults in WMNs, node failure, communication failure, routing failure, scalability issues, network dynamics, and base station and backbone failures. Then we discussed the recent approaches and techniques developed for fault diagnosis and recovery in WMNs. The taxonomy of the presented approaches include: fault diagnosis, node failure, communication issue, routing schemes, fault tolerance mechanisms, and autonomous reconfiguration systems. Also some of the issues to improve QoS in WMNs are mentioned for further research.

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