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A Survey on Multipath Routing Algorithms in Wireless Mesh Networks

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ABSTRACT: Multipath routing allows building and use of multiple paths for routing between a source-destination pair. It exploits the resource redundancy and diversity in the underlying network to provide benefits such as fault tolerance, load balancing, bandwidth aggregation, and improvement in QoS metrics such as delay. There are three elements to a multipath routing, namely, path discovery, traffic distribution, and path maintenance. Path discovery involves finding available paths using pre-defined criteria. A popular metric is path disjointness, a measure of resource diversity between paths. Traffic distribution strategy defines how concurrently available paths are used, and how data to the same destination is split and distributed over multiple paths. Path maintenance specifies when and how new paths are acquired if the states of currently available paths change. There are numerous multipath routing protocols proposed for wireless ad hoc networks, exploring characteristics in mobility, interference, topology, etc. We present a selection of these protocols and give a discussion on how multipath techniques an be extended to wireless mesh networks. Lastly we briefly describe the path selection framework in the current proposal for IEEE 802.11s mesh standard. Although the proposal does not define use of multipath routing, its extensible framework for path selection provides provision for such protocols to be implemented.

I. INTRODUCTION

Multipath routing is a technique that exploits the underlying physical network resources by utilising multiple source destination paths. It is used for a number of purposes, including bandwidth aggregation, minimising end-to-end delay, increasing fault-tolerance, enhancing reliability, load balancing, and so on. The idea of using multiple paths has existed for some time and it has been explored in different areas of networking. In the traditional circuit-switching network, alternate path routing [1] was used to decrease the probability of call blocking. In this scheme, the shortest path between two exchanges is used until it fails or reaches its capacity, when calls are routed through a longer, alternate path2.

In data network the idea of using multiple paths for end-to-end transport first appeared in [2]. One of the earliest distributed multipath algorithms was formulated by Gallaher [3]. Based on the assumption of stationary input traffic and unchanging network, the computation framework converges to minimise the overall delay in the network. The major drawback of

1 National ICT Australia is funded by the Australian Department of Communications, Information & Technology & the Arts and the Australian Research Council through Backing Australia’s ability and the ICT Centre of Excellence Program. 2 In this paper we use the terms path and route interchangeably in the context of data networks

II. GALLAGER’S ALGORITHM

It is very difficult to implement in the real world, given that each router needs to have knowledge of a global constant, which is impossible to determine for all conditions [4]. Also since the adjustment of parameters in each router is initiated by the destination and is done in iterations, the algorithm tends to converge slowly, or does not converge at all, therefore restricting its use for networks with stationary or quasi-stationary traffic. For these reasons, Gallager’s method is used for obtaining theoretical lower bounds only. A number of improvements to the algorithm have since been proposed. In [5] an extension of Gallager’s algorithm using second derivatives was proposed to improve the speed of convergence and parameter selection.

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Multipath Routing

As mentioned before, multipath routing can provide a range of benefits. In the section we describe how these benefits are achieved, and give an overview of the main elements in multipath routing protocols.

A. Benefits of multipath routing

A..1 Fault tolerance

Multipath routing protocols can provide fault tolerance by having redundant information routed to the destination via alternative paths. This reduces the probability that communication is disrupted in case of link failure. More sophisticated algorithms employ source coding [11] to reduce the traffic overhead caused by too much redundancy, while maintaining the same degree of reliability. This increase in route resiliency is largely depended on metrics such as the diversity, or disjointness, of the available paths. We delay the discussion on disjoint routes until the next section.

A.2. Load balancing

When a link becomes over-utilised and causes congestion, multipath routing protocols can choose to divert traffic through alternate paths to ease the burden of the congested link.

A.3. Bandwidth aggregation

By splitting data to the same destination into multiple streams, each routed through a different path, the effective bandwidth can be aggregated. This strategy is particular beneficial when a node has multiple low bandwidth links but requires a bandwidth greater than an individual link can provide. End-to-end delay may also be reduced as a direct result of larger bandwidth.

III.COMPONENTS

There are three main elements in multipath routing, viz. Path Discovery, Traffic Distribution and Path Maintenance. International Journal of Computer Applications (0975 – 8887) Volume 125 – No.14, September 2015 13 3.2.1 Path Discovery. The path discovery component is responsible for the selection of multiple paths between source-destination pairs. Multiple Paths are distinguished based on the property of disjointedness. Node-disjoint paths have no intermediate nodes in common and are resilient to node outages whereby failure of certain nodes only breaks the paths that flow through those nodes. Link disjoint paths have no links in common but may share nodes. They are not as reliable as node-disjoint ones as failure of a node disrupts all links incident on the node. Node-disjoint routes may not always be available, especially in low node density WMNs. To overcome this problem, Lee et al introduced the idea of using maximally node disjoint paths in [14] where the number of links they have in common is at a minimum. 3.2.2 Traffic Distribution there are three constituent parts of the traffic distribution component. They aim to answer three fundamental questions respectively – How are the paths used? How is the traffic distributed between the paths?

What is the allocation granularity? Path usage determines whether all the discovered paths or a subset are used and if they are used concurrently [3, 8, 10, 5] or based on some other scheduling scheme such as the use of the alternate path as a backup of the primary path [4]. Traffic distribution is concerned with the quantum of data that is apportioned to multiple paths. The aim is to balance the load between the available routes. A uniform distribution strategy such as a round robin scheme equally distributes the available traffic [17].

Whereas a non-uniform traffic distribution scheme decides the amount of traffic allotted to each path as a function of certain metrics such as the congestion level of nodes along the path [16, 13]. Allocation granularity, decides whether the traffic is to be distributed on a per packet [9] or per connection basis. Per connection means that all packets of a connection are sent along the same chosen path. Per packet allocation strategy on the other hand, may choose different paths for different packets. Krishnan et al have shown that per packet allocation allows finer control of network resources and therefore provides better performance [12]. 3.2.3 Path Maintenance. Wireless links are unreliable and paths found during the discovery phase may cease to exist due to node or link failures. Path maintenance deals with the discovery of alternate paths when existing paths fail. Path discovery procedures may be initiated either when one path fails or it may be delayed till all paths fail. The latter strategy adds latency and may be unsuitable for QoS sensitive applications, while the former entails performing path discovery every time a single route fails which incurs high control overheads. A suitable trade-off must be chosen by the routing protocol.

A. Issues in Multipath Routing

While there are many benefits of multipath routing, challenges still have to be addressed. It has been argued that unless a large number of paths are discovered load-balancing in multipath routing may not be achieved [6]. However, it has

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Vol. 6, Issue 11 , November 2019

also been shown that such conclusions may be valid only for scenarios where nodes continuously send data to other nodes via shortest paths [8] and traffic patterns in WMNs do not belong to this model as data flows primarily from nodes to gateways. Traditional TCP does not perform well when multiple paths are used to route data [7, 11]. Packets of a flow routed through multiple paths may arrive out of sequence at the destination, leading TCP to assume congestion and trigger congestion control by reducing the data transmission rate. Another problem is that when multiple paths are used each path will have a different round trip time (RTT) which leads to inaccuracies in TCPs RTT estimation. To overcome these problems some researchers have suggested the use of multipath aware TCP such as SCTP [18] and have contended that such TCP coupled with multipath routing leads to significant performance benefits. Another serious problem afflicting multipath strategies is that of route coupling. It occurs when multiple paths of a flow lie close to each other, typically along the shortest path, resulting in inter-path interference. To overcome the negative effects of route-coupling, solutions such as using multiple channels to build contention-free paths [19] and use of directional antenna [20] have been proposed. However such solutions require additional resources which may not be feasible. Schemes such as [8] aim to tackle the route-coupling problem by using a two round route discovery process to establish a protective region of "in-region nodes" around the primary path. Others use interfering links to provide a protection path around the primary path [10]. Still others make sure that paths are sufficiently spaced apart in terms of spatial distance to ensure that they are inter-path interference free [5].

IV. OVERVIEW OF MULTIPATH ROUTING ALGORITHMS

A. MMESH

Nandiraju et al present a multipath hybrid routing protocol coupled with a traffic splitting algorithm that load balances the traffic [17]. MRs on receiving gateway advertisement messages set up paths to these gateways in order of their performance based on a metric (such as ETT, load etc. . .) MRs then send a PARENT NOTIFICATION message containing information of all chosen routes, to their parent MRs from whom they have received the advertisements. In this manner child MRs notify their parent MRs which paths to use for forwarding traffic and also enables parent MRs to establish reverse routes to the child. CHILD NOTIFICATION messages are then sent by the parent MR to all MRs that are part of the selected routes which is propagated all the way to the gateways. This notification informs all intermediate MRs of child MR and the paths to reach the child MR. In this manner multiple routes from MRs to gateways are constructed. Route maintenance is done by MRs periodically monitoring the paths that pass through it and immediately informing its neighbours if it encounters new or stale routes. On detection of a failed next hop an MR suspends the transfer of data through the node for a threshold time pending the recovery of the node when the route is made active again. If the node does not recover within the threshold time the source is notified via a route error message.
MMESH offers two methods for traffic distribution – the first is the round robin scheduling scheme that routes every packet to a different next hop. The second method adds a congestion aware component that looks at the average queue length of the next hop node and based on the load sends the packet or temporarily skips that node and uses an alternate route. However, the protocol does not address the route coupling International Journal of Computer Applications (0975 – 8887) Volume 125 – No.14, September 2015 14 problem. It is designed for a single radio mesh network and therefore does not exploit the benefits of multi-radio architecture. Furthermore it does not support splitting of data of a single flow to multiple gateways. The authors analyse the working of the protocol through simulations. They show that in comparison to the ADOV protocol, throughput of flow increase significantly when congestion aware MMESH is used.

B. ASMRP

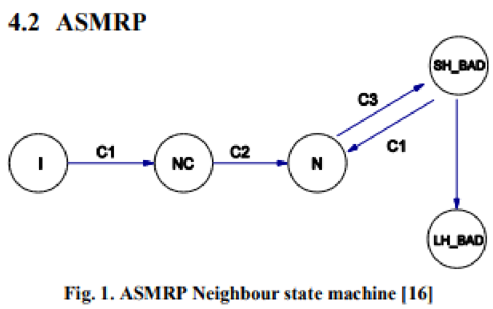

Fig. 1. ASMRP Neighbour state machine [16]

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Nandiraju et al extend MMESH to multi-radio mesh architecture and present an Adaptive State-based Multi-radio Multi-channel Multipath Routing Protocol (ASMRP) [16]. The mesh network is modelled as a multi-level hierarchical structure with the gateways at level 0. MRs below the gateway is assigned levels based on the hop distance from the gateway. Each MR is equipped with four radios - One radio is used for connecting the router with its client nodes. Another is used to send and receive broadcast messages and the remaining two radios are used for sending and receiving data. The receiving radio is tuned to a fixed channel while the sending radio is switchable and keeps changing channels. To communicate, a MR tunes its sending radio to the channel on which the receiver radio of the peer router is operating by consulting a Neighbour Channel Table (NCT) that is maintained in each MR.

The NCT records the channel frequency neighbouring MRs receiver radio are tuned to. Route setup and traffic distribution are based on MMESH. Additionally, ASMRP uses a state machine to maintain multiple routes. MRs can exist in any of the states depicted in figure 1 and transitions occur when certain conditions are satisfied. MRs Transition from one state to another when certain conditions are satisfied. A node is in the initial state "I" when it boots. On receipt of any HELLO message (condition C1), a MR moves to the neighbour candidate (NC) state and it can be used as a potential next hop. An MR is in the neighbour (N) state when the link between it and the current MR is stable. MRs transit to this state when a number of HELLO messages are received from it (condition C2). A neighbour of an MR enters the Short-term history bad (SH BAD) state when its link with the MR is not stable for short period of time (condition C3). When a neighbour enters this state all routes through it is temporarily disabled till the link improves again and the node moves back to N state. However if an MR has no other route it will still use the SH BAD neighbour to route data. LH BAD is the state of a neighbour when the link from the MR to it is bad over a longer period of time (condition C4).

In such an event all routes through the affected neighbour is deleted from the neighbour list and the MR looks to form alternate routes. By designating a state to each MR, ASMRP determines which nodes may be used to route data. Another optimisation ASMRP proposes is to store routes and additional state information in the intermediate MRs assigning labels to the routes and sending out these labels in periodic announcement, avoiding the large network overhead of source routing protocols.

ASMRP provides improvement over MMESH due of the use of multiple radios which mitigates the problem of route coupling. However the extent of the improvement depends on the channel assignment scheme employed. By authorising intermediate nodes to route data over to alternate routes when a node or link failure is detected, ASMRP provides local recovery from route failures which improves its performance vis-sa-vis similar protocols. A big disadvantage however, is that it does not support multiple gateways. NS-2 simulator is used to compare the performance of ASMRP with AODV, MMESH, MMR, and CAM-ASMRP. ASMRP provides better aggregate network throughput than the other protocols. It also outperforms other protocols with regards to packet delay due to the use of multiple radios that can provide full duplex transmissions. By using congestion aware traffic distribution strategy, ASMRP provides better packet loss ratios and increases reliability of data delivery.

V. CONCLUSION

Wireless mesh networks are vulnerable to wide range of security attacks because of their deployment in an open and unprotected environment. This research work investigates different wormhole detection techniques, examines various existing methods to find out how they have been implemented to detect wormhole attacks. Each technique has its own strength and weaknesses. We presented an efficient mechanism to prevent Wormholes on WMN. The proposed mechanism is simplistic and does not rely on additional like GPS systems. The implementation of the proposed method is provided using the NS2 environment. For performance analysis is performed using the generated network traces. The performance of the implemented routing method is estimated in terms of packet delivery ratio, throughput, and end to end delay.

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