International Journal of Scientific Research in Computer Science and Engineering
Research Paper Volume-3, Issue-2 ISSN: 2320-7639

Relevance Multipath Forwarding in Intended Wireless Mesh Networks

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Available online at www.isroset.org

Abstract- The concept of Wireless Mesh Networks (WMNs) is getting huge response in the last years as a cutting in the cost as an alternative to traditional wired access networks. In the framework of WMNs assets are basically insufficient, which have lead to the scheme of dynamic routing in order to completely utilize the network facility. We fall out as a substitute in favor of extrication routing from forwarding. In this proposal a uniform load-balancing scheme is proposed in which it forwards incoming packets along with several already established paths in order to reduce a definite congestion function. In this scheme we consider a picky but very typical scenario where, a deliberate WMN where all links do not get in the way (interfere) with each other. We use an easy and adaptable congestion function, in that function the sum of the average queue length in excess of all network nodes interfaces. This scheme presents a method to learn this function through measurements and numerous simulations to demonstrate the structure, while match up to our scheme with IEEE 802.11s standard.

Index Terms— Wireless Mesh Networks, Traffic Engineering, Load-Balancing

I. INTRODUCTION

The Wireless Mesh Networks (WMNs) [1] are nix no longer only a assure for the future but a reality today, thanks mainly to the advantage offered in terms of cost compared to traditional wired access networks. In particular, outdoor community mesh networks [2] and rural deployments [3, 4] based on IEEE 802.11 have seen tremendous growth in the recent past [5]. An example lately even service providers are beginning to use this technology, resulting in an increasing presence of carrier-class equipment in the market [6]. Under this scenario, the typical architecture (see Fig. 1) includes one or more internet gateways and several relay routers. Clearly, this intermediate routers increase the coverage of the access network without requiring more and probably expensive, connections to the internet. However, several problems arise that are specific of this kind of architectures. The main challenge for this kind of networks, at the wireless mesh backbone level, is routing and forwarding. In the current IEEE 802.11s standard [7] (and in several other proposals [8]) each link has an associated metric value as cost. This cost is expected to change over time, and reflect current conditions (propagation conditions, interference, etc.), so as to maximize a certain criteria (e.g. throughput). To choose a path to its destination, each router executes a shortest path algorithm. This procedure is essentially the same than the one used in wired networks. The main difference is that, just like in the Internet until the early eighties, link costs are allowed to change at a time scale of some seconds [9]. The more static configuration that is used nowadays is due to the oscillations caused by these dynamic costs. This looks like history is repeating itself, after initial experiments with WMNs have also reported routing oscillations [10,11].

However, a completely static routing approach is not a suitable solution in this context. Static means non-optimized routing. In the wired case this is not such a big issue, since resources, especially in the core, is relatively inexpensive (in fact, most core networks are over provisioned). On the contrary, in wireless networks resources are intrinsically scarce, and ‘‘upgrading’’ a link’s capacity is not always a possibility. Existing assets must then be used at its highest, and for this purpose a certain form of energy must required.

We present a novel approach which separates routing from forwarding, just like MPLS does in the wired context. That is to say, each access router has several possible paths towards the destinations and that path remains unchanged as long as no topological change takes place (e.g. a node failure). Please note that in the context of WMNs we may safely assume that nodes are fixed and do not change status nor position very often.

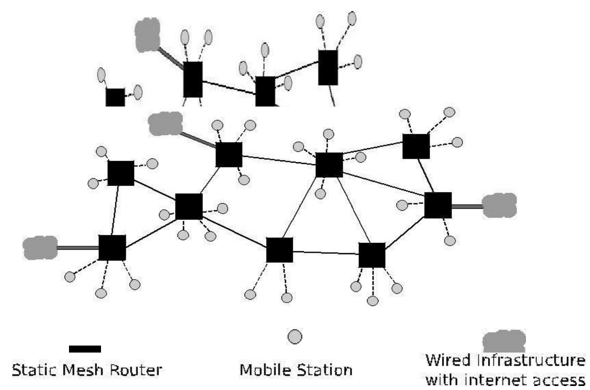

Fig. 1. Wireless Mesh Network (WMN) typical architecture

When we judge a picky but very typical situation in that case a planned WMN, anywhere all bidirectional point-to-point links do not interfere with each other. This assumption means either that all backhaul links use different channels or that links in the same channel are in different collision domains. There are many scenarios where this assumption holds, for example suburban or rural area networks and even campus networks, deployed with high directional antennas with proper RF design and channel assignment. This assumption also implies that the network topology is already defined, typically at infrastructure deployment phase. This means we can-not decide which backhaul links to establish but only how to use them, i.e. which traffic route through them.

The question that remains is to what purpose should load-balancing serve and be worthwhile. That is to say, what function of the traffic distribution should be optimized (where ''traffic distribution'' refers to the portion of traffic sent along each path). In this paper we argue that this function should be the sum over all nodes' interfaces of the corresponding average queue length. As shall be discussed in Section 3, this is a very versatile and important performance indicator. The problem we address is then to find the traffic distribution that minimizes the sum over all interfaces of the aver-age queue size. However, instead of relying in analytical expressions based on (arbitrary) models, we will strive at reflecting reality as much as possible, and design a measurement-based scheme. In this framework the relationship between the average queue length and the current traffic distribution will be learned from measurements, and the optimization shall be performed based on this learned function.

We suggest a load-balancing framework for multipath forward in 802.11 WMNs and for that we show the advantages for this kind of net-works. We compare the performance of the proposed method with static routing through shortest path and dynamic routing using 802.11s. Several simulations over canonical topologies show the advantages of the proposed scheme over the alternatives. The proposed framework also copes with the gateway selection problem, typically present in WMNs. The deployment of WMNs in recent years has grown and is expected to continue rising, so it becomes essential to find a proper routing/forwarding to provide adequate service to the also growing traffic demands. The results we present suggest that dynamic load-balancing is an excellent candidate.

The rest of the paper is structured as follows. In the next section we describe some previous work and highlight some recent papers. In Section 3 we introduce the network model and most of the notation used in the paper. The paper continues in Section 4 where we describe the procedure for learning the congestion function model from measurements, while in Section 5 we detail the operation of the proposed method. Finally, in Section 6 we present the simulation experiments and performance comparison, while conclusions and future work are discussed in Section 7.

II. Related Study

In the context of WMNs, several previous works presented new metrics for single path routing that take into account information from lower layers [8]. The need to increase the WMNs capacity led to the use of nodes with multiple radio interfaces which was analyzed in [16,17]. In this paper we consider a deliberate WMN, in which all links do not mess with each other. Even in an unplanned scenario several algorithms have been proposed [18–20] which could be used to schedule the links so that they do not interfere with each other.

There are some recent related works that we would like to highlight. In [21] an optimization framework is presented to reach minimum average delay per packet in a single channel WMN. Starting from a Markov chain model for the medium access of a single node, they derived a closed form representation for the average system delay which is used as the objective function. The model takes into account the neighbors interference but several parameters of the Markov chain need to be calculated or defined which could difficult the implementation.

Another work that uses an analytical model in the context of single channel WMNs. In particular, the authors developed a queuing-based model which is used to estimate the network capacity and to identify network bottlenecks. Based on a load-aware routing metric they choose the corresponding path for each new incoming flow, and then based on the model a centralized entity performs admission control to guarantee network stability. They focused on per-flow performance and compare the results with shortest-path first routing algorithm.

Concerning dynamic gateway selection, in [23] a heuristic algorithm was proposed to tackle the problem. A distinct channel WMN is measured between routers, when operating in a different channel than links between WMN nodes and mobile hosts. They assume that a routing protocol is executed in the WMN which establishes routes between every pair of nodes, including the gateways. They seek to minimize the maximum number of flows served by a gateway and minimize the cost of paths in order to avoid interference in the network. Contention regions are modeled as the maximal cliques of the contention graph, which leads to a Mixed Integer Nonlinear Programming (MINLP) formulation of the problem. Their proposal solves gateway selection for internet flows in a centralized manner using a greedy heuristic.

To the best of our knowledge, the only work that proposes a forwarding scheme for WMNs is the recent article [24], where the authors present an MPLS-based forwarding paradigm. However, two important differences with our proposal should be highlighted. Firstly, they allow traffic splitting at every node in the net-work while we only allow it at access routers. Secondly, and most importantly, they considered the hose traffic model (only knowledge about maximum traffic demands) which leads to a robust routing fashion to solve the problem. The optimization cost function of a routing solution is calculated as the average over all the feasible flows allocations, where the function used is a weighted average of the total utilizations over all the collision domains. When we talk about WMNs, it is more suitable to consider a dynamic load-balancing solution rather than a robust routing scheme, because it is exactly in scenarios with highly dynamic traffic like WMNs where the former takes advantage over the latter. For a deep comparison between both methods please refer to [25].

All in all, two major differences should be distinguished between our proposal and previous works. The first one is the introduction of a measurement-based model for 802.11 links,

ISROSET- Int. J. Sci. Res. in Computer Science & Engineering Vol-3(2), PP (5-10) Apr 2015, E-ISSN: 2320-7639

whereas most of the literature is based on (arbitrary) MAC layer models like the one presented in Bianchi's seminal paper [26]. The second important difference is the time scale at which decisions are taken. Most of routing algorithms proposed for WMNs are based on a certain metric which changes at a time scale of seconds. Our frame-work operates with averages taken over tens of seconds and forwarding decision is taken with flow granularity. This fact enables decoupling the link model learning phase from the forwarding decision, and ensures better stability properties avoiding route flapping problem.

III.PROBLEM IDENTIFICATION

Firstly, let us remark that in the context of WMNs we may safely assume that nodes are fixed and do not change position very often. In addition, power supply is not a problem, so we will completely ignore energy consumption. We will then concentrate on the performance as perceived by packets in terms of delay, dropping probability and throughput. Naturally, we will limit ourselves to the WMN, which means that throughput will refer to a quantity proportional to the inverse of the time that it takes any given packet to leave the network.

Before introduce the notation, first we have to highlight that throughout this paper we will assume that each node has a single FIFO queue attached to each of its (possibly several) interfaces. This means that all packets at each interface will receive the same treatment, independently of its destination, number of traversed hops, etc. This is not a very problematic assumption, since the only queue management that most wireless routers implement is some form of prioritization of certain particular and few packets (e.g. ARP packets).

Let n ¼ 1; . . . ; N be the set of static wireless mesh routers (including gateways) which we shall call nodes and l ¼ 1; . . . ; L

The backbone bidirectional links in the network. Typically, high gain directional antennas are used for backhaul links with other nodes and sector panels or unidirectional antennas are used to provide connectivity for mobile stations. Gateways nodes have also wired links to a fixed infrastructure network with internet access. We will focus on the mesh core, so only backhaul links and aggregated traffic at mesh routers will be considered. Traffic generated at node n will refer to all traffic arriving at n from the mobile hosts attached to it. We will assume that this traffic uses different channels (e.g. 802.11b/g) than the ones used within the mesh core (e.g. 802.11a). If n is a gateway, the generated traffic also includes that coming from the internet to nodes in the WMN. As we mentioned before, we shall further assume that channels within the mesh core do not interfere with each other. Moreover, paths are assumed to be established a priori and how to choose them is out of the scope of the present paper. In particular, we will use the k shortest paths.

Let us now discuss with more detail what this delay is com-posed of. Once a packet enters a node interface queue, it has to wait for several things to happen. Firstly, it has to reach the head of the line of the queue. What happens after then depends on whether the node is a gateway and the packet goes to the inter-net, or not. In the former case, it has to wait for all its bits to be sent by the wired interface. In the latter case, it has to wait for the channel to be idle. Once this happens, the packet has to be

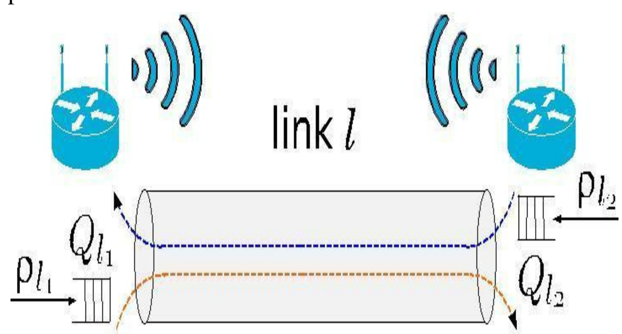

Fig. 2. Wireless link queues and flows in both directions.

IV.PROPOSED APPROACH

The application of the proposed framework in a real-world net-work is relatively simple. First of all we need a routing protocol to establish the multiple routes for each OD pair defined by the wire-less network topology. Once we have learnt Ql for every link represent l, every access router receives the values Ql from the links used by the OD flows with beginning in that access router. A routing protocol that supports information distribution such as OSPF-TE may be used for this purpose. With that information, each access router is able to update the traffic portion that has to be routed through each path. This process is repeated indefinitely every some seconds.

With respect to the flow-based multipath forwarding implementation, the idea is to use an MPLS-based solution, similar to the wired case. Although a standard of MPLS over WMNs does not exist yet. This scheme could be executed for reusing the same splitting-based scheme, but considering splitting only at access routers over all the different end-to-end paths and enabling dynamic load-balancing for the average load at each moment.

Regarding the learning phase we envisage several possibilities differing in the resulting architecture. One possibility is that a central entity gathers the measurements, performs the regression and communicates the obtained parameters to all access routers. This option has the advantage that the required new functionalities on routers are minimal. However, as all centralized architectures, it may not be suitable for some network scenarios, and handling the failure of this central entity could be very complicated. They should keep the average queue size measurements for the scheme, it execute the regression and communicate by the result to the access routers.

Another aspect that has different possibilities is what characterization use at each moment and which measurements to keep for the training set. Measurements could be gathered every day, the regression performed, and its result could be used the next day or the same day the next week. In addition, it is clear that newer measurements should be given priority over older ones. A possible way to manage training data is to keep always the newer measurements and use weights in the regression to introduce temporal information (e.g. exponential decay). It may also be necessary to force keeping particular measurements to en-sure a proper coverage density of the whole load value range.

Relating to the number of measurements required for training, we have to show how the measured learning algorithm does not need a large number of measurements, as long as the training samples adequately covers the whole range of possible.

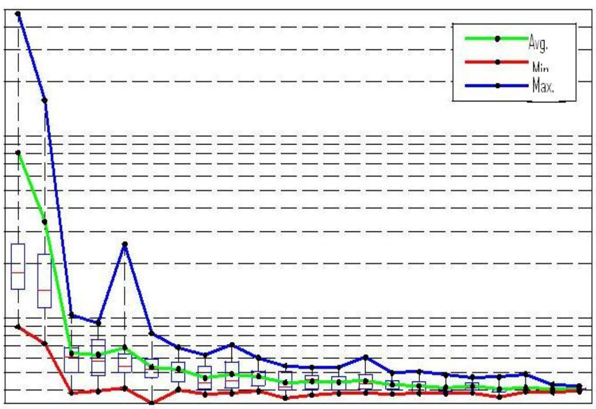

Fig.3:Size of training set

Finally, rare events like node failures or changes in propagation conditions can be taken into account in our framework as follows. If interference on a particular link changes, this is captured when the learning of the function associated with that link is repeated. As we mentioned before, this learning process is periodically repeated. However, if several new measurements differ greatly from the learned model, one could decide to trigger a new learning process. Moreover, if a node fails, the access routers will not receive the corresponding link load information. If no such announcements are received for a certain period of time, this should lead to the decision of disabling all paths that use the faulty router.

V.EXPECTED OUTCOMES

The given scheme can be able to:

a) Flow sorting can be executed in a will uniform manner.
b) WMN's improve the traffic at Intermediate Gateway.
c) Monitoring can be performed based on congestion control based on WMN's.
d) The underutilized node problem can be solved.
e) WMN's provide the route balancing in an effective manner.
f) Flow can be locked down or diverted at a specified time for a particular duration.
g) Flow classification can be done in a controlled manner.

VI. EVALUATION FACTORS

6.1 Multipath forwarding: 3-nodes topology:

The first example is presented to illustrate the framework and corresponds to the topology and flows shown in Fig. 4. This topology has three links 1, 2 and 3, which implies we have also three functions Q 1; Q 2 and Q3, each of them corresponding to the sum of the link queues in both directions. In this case we considered flows from node 1 to nodes 2 and 3 with traffic loads d1 and d2 respectively. When we apply the described framework to this particular topology and the considered traffic flows, we have the following function for the average end to end queuing delay in the network:

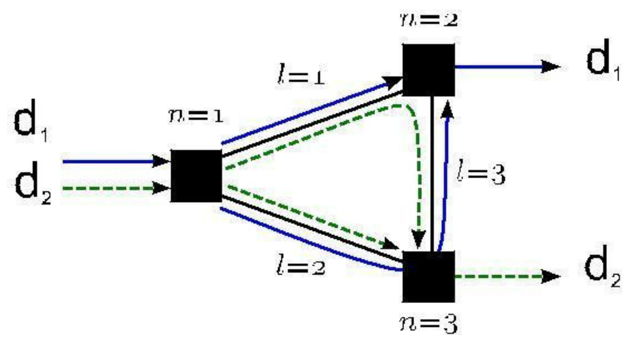

Fig. 4. 3-Nodes topology multipath forwarding example.

6.2Gateway selection problem

In this subsection we will analyze an example corresponding to the gateway selection scenario shown in Fig. 12. We will show that it is possible to solve this problem under the proposed framework, treated as an equivalent multipath forwarding one. In this topology we considered downlink flows to nodes 3 and 4, with demands d1 and d2 respectively, which can be distributed between the two gateways GW 1 and GW 2. Notice that both gateways could be considered as the same traffic origin (internet). We can think this origin as a super node, connected to both gateways by links with infinite capacity (shown with dashed lines in Fig. 12). Then, the gateway selection problem turns into a multipath forwarding problem, where we have to decide which portion of traffic demands d1 and d2 to forward through each of the possible paths from the super node (internet), which is equivalent to decide which portion of traffic to route from each gateway.

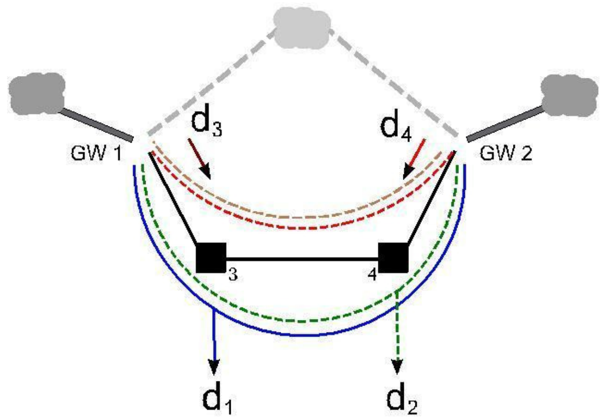

Fig. 12. Gateway selection problem

VII. Conclusion & Future Work

In this paper we proposed an algorithm for dynamic multipath forwarding in a WMN. The algorithm enables load-balancing and conducts the network to operate at the minimum average congestion. The proposed framework also allows solving the gateway selection problem in a WMN. This was achieved learning the average queue length function from measurements for each link and applying an optimization method in order to reach the minimum average queue length in the network. When a uniform evolution and junction for the proposed method was verified by our packet-level simulations larger than several canonical topologies which served as a proof of concept.

We further analyzed the simulations taking several flow-level performance metrics as average delay and jitter for UDP traffic and average good put for TCP traffic. With this metrics we studied the performance of the proposed MQLLB method compared with the IEEE 802.11s standard. The results show a clear advantage of MQLLB against a dynamic metric routing method like the one used by 802.11s. In all the simulations, independently of the topology size, we observed a quick adaptation of MQLLB to traffic changes and also a stable operation, avoiding the routing oscillations of 802.11s. [11,29].

In our future work we will perform the learning phase with real data which includes among other issues the non-zero channel error rate, usual in a real-world wireless link. All the simulations presented in this paper are done with synthetic traffic, so we would like to extend our work using real traffic data. It would also be very interesting to perform a statistical analysis of the behavior of the mean queue size with respect to the load. A possible analysis would be to study how often does the regression function change over time (i.e. answer the question of whether the mean queue size function changes over time, and how often it does).

Another aspect of our future work is the implementation of the proposed framework in a real-world network which was briefly discussed in this article. One possible way is to explore the adaptation of a recent MPLS-based routing scheme for WMNs [24] to our proposal. A tested deployment would be useful for enhancing the algorithm and detecting real-world driven problems that need to be solved. An interesting point which could be more profoundly studied in the future is the optimization phase. When we looking towards this problem it could be solved by several different methods and was not analyzed in the present paper. Finally, we would like to extend the proposed framework, which was developed for links disjoint WMN, to scenarios that have not only point to point links but also point to multipoint links.

Acknowledgment

This work is proposed as the study level of PhD in wireless mesh network under the granted research at Pacific University. We also thank our anonymous reviewer for their feedback which helped me to improve the quality of the paper.

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