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Distributed Multipath Routing Protocol for Wireless Networks

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ABSTRACT

Routing protocols for multi-hop wireless networks have traditionally used shortest path routing to obtain paths to destinations and do not consider traffic load or delay as an explicit factor in the choice of routes. The main objective is to construct a perfect flow-avoiding routing, which can boost the throughput provided to each user over that of the shortest path routing by a factor of four when carrier sensing can be disabled or a factor of 3.2 otherwise. The protocol is developed that adaptively equalizes the mean delay along all utilized routes from a source to destination and does not utilize any routes that have greater mean delay. This is the property satisfied by a system in Wardrop equilibrium. The routing protocol is 1) completely distributed, 2) automatically load balances flows, 3) uses multiple paths whenever beneficial, 4) guarantees loop-free paths at every time instant even while the algorithm is suntil converging, and 5) amenable to clean implementation.

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INTRODUCTION

A. Wireless Mesh Networks:

A Wireless Mesh Network (WMN) is a communications network made up of radio nodes organized in a mesh topology. Wireless mesh networks consist of mesh clients, mesh routers and gateways. The mesh clients are often laptops, cell phones and other wireless devices while the mesh routers forward traffic to and from the gateways which may but need not connect to the Internet.

- The coverage area of the radio nodes .working as a single network is called a mesh cloud.
- Access to this mesh cloud, is dependent on the radio nodes working in harmony with each other to create a radio network.
- A mesh network is reliable and offers redundancy.

A wireless mesh network can be seen as a special type of wireless ad-hoc network. It as a more planned configuration, and may be deployed to provide dynamic and cost effective connectivity over a certain geographic area.

An ad-hoc network, on the other hand, is formed ad hoc when wireless devices come within communication range of each other. The mesh routers may be mobile, and be moved according to specific demands arising in the network.

B. Wardrop Equlibrium:

For every source-destination (SD) pair, the protocol adaptively equalizes mean delays along all utilized routes and avoids using any paths with greater or equal mean delay. This is the property satisfied by a system in Wardrop equilibrium. Such an equilibrium is potentially useful in practice for a variety of reasons:

1. Adaptive delay-based routing can automatically route around hotspots in interference-constrained wireless networks.
2. Equalizing the average delay along used paths can reduce resequencing delays for packets in receiver socket buffers.
3. TCP congestion control reacts adversely to reordered packets and thus misbehaves when TCP is used over multiple paths. Equalizing the average delay along used routes can reduce packet reordering and potentially improve TCP behavior when it is used on top of multipath routing.

II. *Related work:*

The problem of finding loop-free routes to destinations in mobile environments has been well studied (Clausen, T.,; Johnson, D.B. and D.A. Maltz, 1996; Perkins, C.E., 1999; Park, V. and S. Corson, 1997; Zygmunt Haas, M.P. and P. Samar, 1999; Perkins, C.E. and P.R. Bhagwat, 1994; Royer, E. and C.K. Toh, 1999). Proactive protocols (Park, V. and

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S. Corson, 1997; Perkins, C.E. and P.R. Bhagwat, 1994) maintain routes to all destinations and incur a large routing overhead. Reactive protocols, on the other hand, construct routes on an on-demand basis using a route is covert procedure. Multipath extensions of existing on-demand protocols can provide recovery from route failures. For example, CHAMP (Alvin Valera, W.S. and S. Rao, 2003), built on top of DSR, uses cooperative packet caching and shortest multipath routing to reduce packet loss due to frequent link breakdowns. AOMDV (Marina, M. and S.R. Das, 2001), built on top of AODV, computes multiple link-disjoint paths to a destination by using an advertised hop count. Nasipuri and Das (1999) propose an extension to DSR, where they provide sources and intermediate nodes with alternate paths during the route discovery phase. A technique to allow AODV to install backup routes at the neighbor nodes of a primary route is investigated in (Lee, S.J. and M. Gerla, 2003). Multipath routing can also alleviate congestion in wireless networks. The hotspot mitigation protocol (HMP) can be integrated with AODV and DSR and attempts to disperse new flows from being routed through hot spots and congestion-prone areas. The Dynamic Load Aware Routing protocol (DLAR) carries congestion information forward in ROUTE REQUEST packets, allowing destinations to choose the least congested path. Finally, there is an extensive literature on optimal dynamic routing and its formulation as the solution of an optimization problem. The problem can be equivalently cast in terms of routing variables at each node and a completely distributed algorithm can be derived. An approximation approach to minimum delay routing provides a set of loop-free invariant conditions, while distributing traffic to approximate .The Wardrop equilibrium can be interpreted as the equilibrium point of an optimization problem that minimizes the sum of the integral of delays on all network links. On the other hand, the Wardrop equilibrium differs from a pure delayminimization policy because it takes resequencing delay at the receiver into consideration. As mentioned in the introduction, this work builds on earlier work on design and convergence of delay-adaptive routing algorithms (Gupta, P. and P.R. Kumar, 1997; Borkar, V.S. and P.R. Kumar, 2003). This paper aims to bridge the gap between the theory of Wardrop routing and its implementation and use as a routing protocol in 802.11-based wireless mesh networks and is an extended version of our work described in (Raghunathan, V. and P.R. Kumar, 2004; Raghunathan, V. and P.R. Kumar, 2005).

III. *Objective Of The Proposed Mechanism:*

The goal of this paper is to bridge the gap between the theory of delay-adaptive routing and its implementation and use in practice as a routing protocol for 802.11-based wireless mesh networks. The issues addressed range from theoretical characterization and algorithmic properties to a detailed simulation study and architectural challenges in implementing multipath delay-adaptive routing protocols. This has resulted in our user-space implementation on a custommodified Linux 2.4.20-6 kernel and a measurement study of the implementation on a testbed.

IV.*Adaptive Multicast Routing Protocol:*

A. The Challenges:

Our work on rendering Wardrop routing practical will build on the above algorithm. We will preserve all the valuable features, such as immunity to clock offsets at the nodes. However, to obtain a practical protocol that in fact delivers improved performance; we need to make several modifications. We begin by identifying three problems that render difficult the use of the algorithms presented in:

1. The routes followed by packets are unrestricted. They can be arbitrarily long. This causes several problems:

a. There are many bad routes that packets can go out on and delays experienced by such packets can be exceedingly long.

b. Since the algorithm requires feedback on all these bad routes before it can adapt, its convergence can be very slow, rendering it impractical.

2. After the routing probabilities have converged to the correct estimates, the algorithm produces loop-free routes. However, packets can follow loopy paths while the algorithm is converging, which, in practice, is always the case.

3. The delay measurement in relies on acknowledgments to carry measurements back to sources and intermediate nodes on a per-packet basis. This poses problems in implementation:

a. A scheme relying on transport layer ACKs to solve the network layer routing problem violates layering and does not extend to unreliable transport layers (e.g., UDP).

b. Further, there is no guarantee that ACKs will follow the reversed path as the data packet. Thus, intermediate nodes will not be able to obtain delay information. To address these problems and obtain a practical protocol amenable to deployment, we redesigned the algorithm in to obtain two protocols M-STARA and P-STARA:

1. We propose new mechanisms to control the length of paths followed by packets, while the algorithm is converging. These mechanisms preserve the attractive properties of load adaptation and multipath utilization, while retaining the property of convergence toward the appropriately defined Wardrop equilibrium.

2. We propose a mechanism that guarantees that routes followed by packets are loop-free even while the algorithm is suntil converging. This mechanism is not only compatible with the path length control mechanism above but also continues to preserve convergence toward the appropriately defined

Wardrop equilibrium for the resultant load adaptive multipath routing protocol.

3. We propose a completely distributed delay measurement mechanism to replace the ACK-based scheme with the attendant problems discussed earlier. The new mechanism retains immunity to clock offsets. It consists of a light-weight link delay measurement protocol and a distance-vector like neighborhood broadcast of average delay information. This mechanism is described.

B. The Routing Algorithm:

The traffic-aware routing can provide considerable benefits. However, the scheme used to prove the result is centralized and should only be taken as proof of existence. Instead, we examine a more general adaptive approach. For every SD pair, we will attempt to drive routes toward an equilibrium, where the mean delay along all utilized paths is equalized, and all unutilized paths have greater or equal potential mean delay. In a communication network, such equilibrium has attractive properties vis-a-vis multipath routing:

- When packets have to be resequenced at the receiver and delivered in-order to the application, equalizing the average delay along utilized paths reduces receiver socket buffer space requirements and receiver socket buffer resequencing delays.
- Equalizing the average delay along utilized paths mitigates TCP congestion misbehavior that results from TCP’s adverse reaction to multiple paths and reordered packets.
- Route adaptation using delay feedback allows rerouting of flows around traffic bottlenecks in wireless environments. This allows flows to automatically “avoid” each other and minimize interference. Consider the problem of routing packets over such a network where the performance measure we are interested in minimizing is the expected delay. The setting is a noncooperative one in which each packet wishes to minimize the time taken to get from source to destination. The route chosen by each packet affects the latency experienced by other packets along its route, as well as in the vicinity of its route due to wireless interference. Since each packet has an infinitesimally small impact on the load of the network, the solution of this non-cooperative game corresponds to the Nash equilibrium when the number of agents goes to infinity. For each fs; dg pair in SD, this corresponds to a solution where all flow paths have equal latency, which is lower than the latency experienced on any unutilized path. In the absence of this property, it would be possible for some packet to reduce its latency by switching to the unutilized path. This is the “Wardrop equilibrium,”. Wardrop’s first principle. All utilized paths from a source to a destination have equal mean delays. Wardrop’s second principle. Any unutilized path from a source to a destination has greater potential mean delay than that along utilized paths.

C. Implementation:

One of the most important considerations in the design of the Wardrop routing protocol described in this paper was implementability. In implementing the protocol, we have taken care to ensure that

1. routing policy is separated from forwarding mechanism.
2. components are placed in-kernel only if the user space performance hit is unacceptable.
3. Interfaces are generic, well-defined, and extensible. The architecture of the implementation is shown in The key architectural choice we made was to separate probabilistic packet forwarding from delay estimation. We provide an in-kernel per-packet probabilistic forwarding mechanism consisting of multiple in-kernel forwarding tables. Each table consists of a list of routes to destination. Each route to a destination consists of a vector of two-tuples (next hop, probability of usage). A user-space library provides an API interface to this in-kernel probabilistic forwarding mechanism. This separation of routing policy from forwarding mechanism allows us to cleanly implement different probabilistic route adaptation policies in user space. The protocol logic is almost completely in user space. The link delay measurement module implements the state machines.The average delay measurement module implements a “distance vector”-like protocol to exchange average delay information with neighbors on a periodic basis. The distance vector routing module uses an implementation of DSDV developed at UIUC to produce hop-count information that is used in P-STARA to guarantee loop freedom. The probability update policy module implements various Wardrop route adaptation algorithms, including P-STARA, M-STARA, and STARA. Our implementation fully utilizes advanced kernel routing features like equal cost multipath routing, netfilter, iptables, policy routing, and MARK target routing to minimize the need for kernel modifications. Nevertheless, the implementation needed a small amount of in-kernel mechanism, which we added to the Linux 2.4.20 kernel:

1. Per-packet multipath routing. The Linux kernel implementation of multipath only allows next hop selection on a per-connection basis. This is because the kernel forwarding engine caches routes on a perconnection basis, and all packets of a connection end up using the cached route. Instead of disabling the route cache and incurring a huge performance hit, we tricked the route cache into simulating per-packet multipath.
2. Routing by randomizing one of the keys used for the cache lookup in the Linux kernel. This ensures that the distribution of next hops to a destination in the cache is the same as that in the routing table, up to quantization error. This technique has the added benefit of speeding up the convergence of Wardrop routing in practice as a side effect. This randomization procedure is implemented through the

use of two iptables/netfilter target modules. The TOS_RND netfilter module is attached to the PRE_ROUTING and OUTPUT hooks, while theTOS_UNRND netfilter module is attached to the POST_ROUTINGand INPUT hooks, respectively.

3. Time stamp measurement. This module time stamps and classifies packets based on incoming and outgoing MAC addresses as they pass through the kernel forwarding engine and exports the collected information to user space using the =proc file system.It is written as two net filter/iptables target modules. DELAY_PRE is attached to the PRE_ROUTING and OUTPUT hooks, while DELAY_POST is attached to the POST_ROUTING hooks.

V. *Performance Evaluation:*

A. Simulation Model and Parameters:

In order to understand the protocol behavior, we have carried out an extensive simulation analysis for wireless environments using the ns-2 simulator with the Monarch wireless extensions In all our simulations, we use the two ray ground propagation mode, the IEEE 802.11 DCF MAC, a radio model based on the Lucent Wave LAN 2 megabits per second (Mbps) radio with a radio range of 250 m. We have implemented the Wardrop routing protocols in ns-2 using DSDV as a base protocol to obtain distance information. All of our simulations (except in the section on topology impact) were carried out with N2 nodes on the intersections of a N X N grid. The interface queue length is set to 50 packets, and the retry parameters of the MAC are left at their default values MAC Short Retry Limit ¼ 7 and MAC Long Retry Limit ¼ 4. We use CBR sources with a constant size of 210 bytes running on top of UDP to stress the network. The simulations are run for times between 100 and 3,000 seconds. The parameters for exponential forgetting of average delay measurement and link delay measurement are set to 0.8. The probability of uniform routing to all neighbors, is set to 0.05. Throughput and delay statistics are obtained from ns-2 trace files, while other parameters like routing probabilities, average delay, link delay, routing overhead, etc. are obtained through a custom oTcl interface. For each scenario, we repeated the simulations for 3-5 runs to confirm that the algorithm converged to the same equilibrium.

We use the following metrics to evaluate performance:

1. Throughput-delay performance,
2. End to end Delay,
3. Routing overhead, and
4. Packet Delivery Ratio.

The throughput-delay performance of a routing protocol is a reliable metric in determining its performance in real networks. While auxiliary metrics like routing overhead, end to end delay, packet delivery ratio provide an indicator of how good the performance is, these metrics are already factored into the throughput-delay curve, while the reverse is not true.

B.Throughput-Delay Performance:

To obtain throughput-delay curves for a particular scenario, we load the network progressively until overload, and for each level of network loading, measure the average delay and system throughput. We compare the performance of Wardrop routing to that of the shortest path DSDV protocol. In all throughput-delay simulations, ADP is set to 15.0, LDP to 5.0, and LDPF to 25.0. (These parameters are explained later in this section.) In examining Fig.1, the throughput-delay performance of Wardrop routing is better than the DSDV.

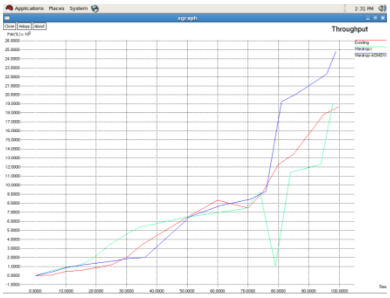

Fig. 1: Throughput Vs Delay.

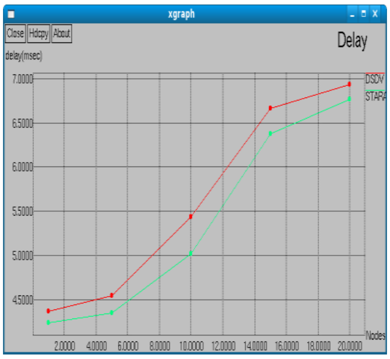

Fig. 2: No.of nodes vs end to end delay.

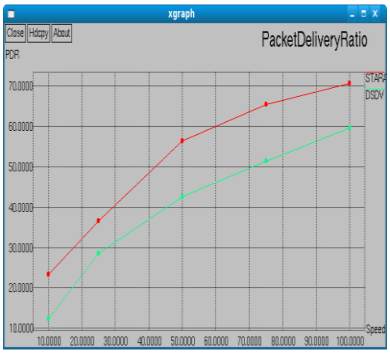

Fig. 3: Speed Vs Packet Delivery Ratio.

Figure 2 show the results of No.of Nodes 2, 20 scenarios. Clearly our STARA scheme achieves less delay than the DSDV routing.

Figure 3 show the results of Speed 10 …100 scenarios. Clearly our STARA scheme achieves more packet delivery ratio than the DSDV routing.

Conclusion:

In this research work, few sources are formally established where flow-avoiding routing provides a four-fold improvement over the throughput of shortest path routing when carrier sensing can be disabled and a 3.2 factor improvement otherwise. Focusing on static wireless net- works, a multipath load adaptive routing protocol have developed.

The mechanisms are proposed to control the lengths of paths and provide loop freedom at all times. The distributed delay estimation procedure is also proposed that eliminates the need for ACK-based delay estimation. Simulations indicate that the protocol appears to be effective in obtaining improved throughput-delay performance gains over shortest path routing in static networks. The protocol have been implemented in user space on a modified Linux 2.4.20 kernel based on an architecture that separates probabilistic multipath routing from delay estimation. A proof-of-concept measurement study indicates the effectiveness of War drop route adaptation. The work on War drop routing at the theoretical, simulation, implementation, and testing levels shows that there is scope for traffic adaptive routing that outperforms minimum hop routing.

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