# MyMANET: A Customizable Mobile Ad hoc Network

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## Abstract

We present MyMANET, a kernel module that provides a framework for ad hoc communication using commodity hardware. It exposes network measurements and provides an interface for inserting a routing protocol. MyMANET is based on a Layer 2.5 approach, which we call the *Wireless Decision Layer* (WDL). Such a system seems suitable for developing regions with infrastructure constraints, where lab-developed solutions often do not work in practice. It models wireless connectivity without maintaining any explicit representation of topology. These features make it suitable for networks with transient topologies or bursty traffic. Here we describe the challenges, design goals and architecture of the system, with a focus on an extreme case of transient topology, namely Mobile Ad hoc Networks (MANETs). We provide an implementation in the Linux network stack including a dynamic, multi-path routing protocol, and evaluate its performance. Unlike proprietary wireless protocols that are hard to reconfigure, our system is easy to use and configure. It addresses the need for rapid prototyping and deployment using commodity hardware.

## 1 Introduction

Our work is directly motivated by the following two distinct scenarios.

Researcher: *"I have developed a cool Wireless Protocol. I don't trust simulation tools. How do I quickly evaluate my protocol in a real set-up?"*

Potential User: *"I live in a village with 200 households. There's just one Internet connection. How can we share access?"*

Transience is observed in most practical wireless networks due to infrastructure failures, interference, physical obstructions, mobility or simply because the nodes are being powered on and off. For example, power failures and interference could make a mesh network have a highly transient topology. Our work applies to such transient networks and makes them more stable and reliable in spite of the unreliability of individual links. We focus on an extreme case of transience, namely Mobile Ad Hoc Networks (MANETs), although our solution applies to networks with more infrastructure as well. MANETs are, in principle, flexible, scalable, power-efficient, and an ideal solution for communication in resource-constrained regions or time periods. MANETs can be set up quickly at any location, whether this be in response to disasters or emergencies; or in regions where economic or infrastructure conditions are not amenable to fiber-based networks; or even zones where broadband is limited or prohibitively expensive.

In spite of these compelling benefits, such networks are not a large-scale practical reality. Although a plethora of multi-hop wireless protocols exist in the literature, there are few real implementations and, unlike wireless mesh networks, no experimental testbeds for MANETs. The technical challenge of a reliable routing protocol for MANETs has not been satisfactorily solved [18] [1]. Part of the reason for this is, MANET — just like any other distributed transient network, is characterized by a decentralized network architecture and a transient network/node behavior. Nodes are scattered around and may come and go any time and at any place. Mobility complicates this further. Whereas protocols for wired networks typically require an explicit representation of the topology, representing wireless connectivity in a compact and scalable way remains a challenge. Due to these and other practical considerations such as ease of use, repeatability and control, simulation has been the dominant evaluation technique [17]. The research community lacks effective tools for large-scale mobile wireless networks and the user community lacks a truly robust and easy-to-use multi-hop mobile wireless solution.

In this paper, we describe the design, implementation and evaluation of a framework for such MANETs. Our design is based on two observations: (a) to be viable in developing regions, equipment should be affordable and reusable. Therefore, the network needs *a commodity platform* for MANET routing protocols, and (b) a commodity platform is possible since multi-hop wireless routing primitives share some fundamental primitives independent of the protocol. These include the following: (b1) monitoring the network and its links, (b2) communicating with neighbors, and (b3) representing routing information in a compact way. Our solution, motivated by these observations, is based on the following design choices:

- The platform should be based on commodity hardware, the standard 802.11 framework for the link layer connectivity and the Linux network stack; it should not require any proprietary hardware or software.
- The platform should expose network measurements and allow routing decisions based on these measurements; in effect, a user should be able to plug in a routing protocol in a simple format.

### 1.1 Our Contributions

Our primary contribution is the design, implementation and evaluation of MyMANET — a Linux based open-source module with the following features:

- A *Wireless Decision Layer* (WDL), used to implement routing decisions. This is a Layer 2.5 approach that does not duplicate functionality of the upper or lower layers and is transparent to both. Standard applications such as file transfer, event distribution services (for emergency communication in case of disaster scenarios) — can be executed *without any modification* on MyMANET using Linux machines with standard wireless chip-sets.
- A *Global Network Statistics Module* (GNSM) that periodically monitors network performance.
- A pluggable *Routing Controller* interface to write customized routing protocols in a simple format and insert into MyMANET for evaluation in a real set-up.
- A dynamic, multi-path routing protocol evaluated in the framework of MyMANET.

We evaluate the performance of MyMANET under real traffic and mobility. In our preliminary experiments with small networks, we find it is highly robust and scalable. We believe it can be a cost-effective solution for communication needs of developing regions, complementing work in providing long-distance wireless links [1, 24, 26]. We argue that MyMANET's ease-of-use, efficiency of implementation and flexibility of routing, make it a viable platform for the realization of mobile ad hoc networks.

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[1] One can argue that this is the case even for multi-hop mesh networks.

## 2 Design

**Architecture.** The MyMANET system consists of 3 parts, namely Wireless Decision Layer (WDL), Global Network Statistics Module (GNSM) and Pluggable Routing Controller.

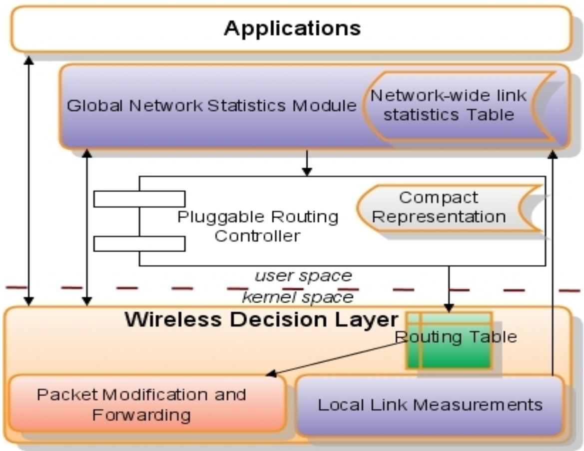


Figure 1: System Architecture

In spite of the potential advantages, we have not modified the link layer because that would require specialized drivers and/or hardware. We believe that the ability to have a commodity platform far outweighs the benefits of having a modified link layer. As illustrated in Figure 1, the WDL resides in the kernel space and handles routing decisions and packet forwarding. It also maintains a real-time count of the number of packets it has sent and received, and exports these counts to the GNSM through well-defined *proc file system* interfaces. WDL also contains a routing table. In our implementation it is a table of *virtual distances* (which suffices for any distance vector based routing protocol). The WDL makes routing decisions based on the information contained in this table maintained in the kernel. The table is updated based on the current state of the network by a combination of the GNSM and the routing controller.

The GNSM at each node transmits and receives *statistics packets*. They contain information that enables each node to estimate the quality of links and end-to-end transmissions.

The pluggable routing controller uses these statistics to maintain a *compact representation*. Given the transient nature of MANETs and the possibly large number of links, updating the virtual distance table based on every statistics packet is not a sound approach. How to maintain the compact representation from the network-wide statistics and how and when to update the virtual distance table is the flexibility provided to the routing controller. Therefore, it can update the virtual distance table when there is a significant change in the state of the network. A configurable *tolerance* parameter is used to control the rate of updates. We mention two examples for illustration: in the case of manifold routing [18], the compact representation is a $k \times k$ table in place of the all-pairs $n \times n$ link quality table, with $k$ independent of the number of nodes $n$ and typically $k << n$. Our simple default routing protocol has a *null* compact representation; a virtual distance is updated only if it is found to have changed by more than the tolerance parameter allows.

**Routing.** Routing in MyMANET is multi-path and dynamic. Routing paths can change during a session based on the state of the network and the environment with little overhead.

*1. Data plane+control plane.* MyMANET provides seamless integration of the data and control plane to provide efficient routing. Every packet contains a *MyMANET Header*.

WDL inserts the MyMANET header between the Ethernet and the network layer headers, in all data as well as control packets emanating from every node. This has 2 implications: (a) Every packet contains control information. (b) Every intermediate node can make a decision about forwarding a packet based on its local state *as well as the current state of the packet*.

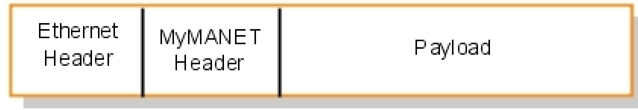


Figure 2: Data Packet Format

*2. Control plane.* Each node maintains information about the end-to-end quality of transmission to every other node. To achieve this, first each node maintains the number of frames sent and received from every other node in a session. Next, each node sends periodic statistics packets indicating the number of frames received from every other node in the current session. These packets are transmitted to every node in a multi-hop manner. Thus, a node $A$ has the number of frames sent ($s$) to any node $B$ and the number received ($r$) by $B$ that originated from $A$ in a session. This information is useful to build a state, based on which control over routing is enforced. For example, in the routing protocol currently implemented, we apply the following transformation 1 to obtain a *distance* measure.

```
//r−> Number of packets received , s−> Number of
// packets sent , d−> Distance
If r >= s then d = ((s/r)*100)
else d = (255 − ((r/s)*155))
```

Listing 1: Calculation of distance

This distance is then used to aid routing decisions.

**Security.** MANETs are vulnerable to security attacks due to their charecteristics of having an open medium, dynamic changing topology, lack of single point of management (SPoM), and lack of a clear line of defense[35]. They typically have independent autonomous mobile nodes without any centralized control. Attacks can be launched using injection of corrupt control packets (with the intent of disrupting the routing activity). Like any other network (wired/wireless), eavesdropping or impersonation can compromise MANET security. Being a Layer 2.5 approach, MyMANET provides standard encryption of content (using SSL, etc), without the need of any further extensions. Unlike the Internet, MyMANET enables each node to have a global view of the network, so it can be more pro-active in monitoring. Using the global view, we can monitor high levels of activity at nodes or on links and apply simple congestion control techniques. This can help localize an attack, detect adversaries and provide each user a fair share of the network bandwidth.

## 3 Implementation

MyMANET has been implemented as a combination of kernel-space WDL and user-space GNSM and Pluggable Routing Controller; and can be run whenever multi-hop routing capability is desired by the network device. The module does not require kernel re-compilation or even a single reboot. Users can download and insert the module onto devices running Linux. They can then form an ad hoc network and move as they desire, run applications and observe network performance.

We will now provide implementation details of each of the three components by considering the core functionality provided by them.

**Local Link Measurements.** WDL maintains a real-time count of the number of frames it has transmitted to other nodes, and the number of frames it has received from other nodes. We call this information as *local link measurements*. In a MANET, typically nodes are mobile and may go out of range of other nodes. Hence, we need to introduce a temporal aspect in the link monitoring logic. WDL has a notion of "Session ID" which increments periodically. Once the session changes, the values of the link measurements of the previous session are exported to GNSM using the *proc file system* interface. Thereafter, the measuring counters are reset and this process repeats for successive sessions.

**Packet Header Modifications.** WDL adds a new header to every outgoing frame. Henceforth, we refer to it as the "MyMANET header". The contents of this header are shown in Figure 3. Original Source MAC address is the MAC address of the node where this frame has originated (not necessarily the previous sender). Thus,

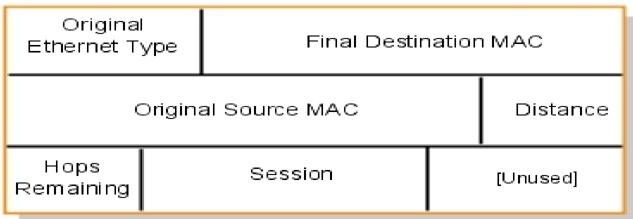


Figure 3: MyMANET Packet Header

for each out-going frame, WDL adds the MyMANET header using its own MAC address as *OriginalSource* and *distance* as its own virtual distance to the final destination (extracted from the virtual distance table). However, for a forwarded frame, WDL retains the MyMANET header, except that it decrements the value of *HopsRemaining* by 1. If a received frame is destined to itself (final destination MAC is of current node), WDL removes the MyMANET header before handing over the frame up to the network stack for further processing.

**Packet Forwarding.** For each frame received: (a) The module extracts control information from the MyMANET header. A very important field of this control information is "distance" which represents the cost of sending a frame to its final destination. (b) looks up the current distance of this node to the final destination of the frame in the virtual distance table. (c) forwards the frame only if the virtual distance of the current node to the final destination is less than the distance in the MyMANET header of the frame. Based on this comparison, it queues the frame for re-transmission - after updating *distance* to its own virtual distance to the final destination; or drops it after updating statistics. Thus, the frame forwarding decision is based on the local state as well as the state mentioned in the packet.

**Updating the virtual distance table and Routing.** As shown in Figure 4, GNSM creates statistics packets and transmits them periodically. The information collected by GNSM is shared with the routing controller which maintains a compact representation of the state of the network and updates the kernel-space virtual distance table based on the changes in the compact representation.

```
null_routing_controller(MAC_ADDRESS receiver, int r, int s){
//Calculate the distance to receiver using number
//of packets this node had sent in a session, and
//the number of packets received by the receiving
//node in that session.
    distance = calculate_distance(r, s);
    //GNSM_Distance_Table stores the distances
    //to other nodes in the network from this node.
    change = (distance - GNSM_Distance_Table[receiver]);
    if((abs(change) > TOLERANCE)){
        //Update the kernel space Virtual Distance Table
        update_virtual_distance_table(receiver, distance);
    }
}
```

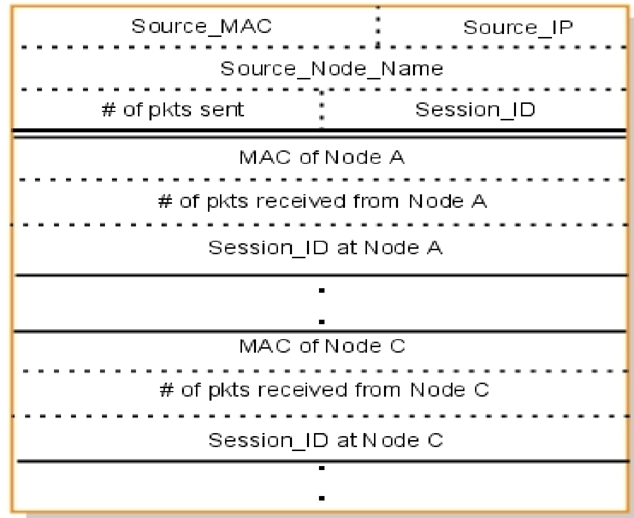


Figure 4: Statistics Packet Format

Listing 2: Simplified Routing Controller

The routing controller is the piece that can be modified to evaluate different protocols. To illustrate the ease of use, we include a small piece of code 2 which implements a *simplified* routing controller. The GNSM executes this code when a node (*receiver*) reports that it received *r* packets out of the *s* packets sent by this host.

Typically, the state of individual links changes rapidly in MANETs. Updating the kernel space table after every change can be expensive and cause instability. We use a *tolerance* parameter to control the number of updates sent to the kernel-space table.

# 4 Evaluation

We evaluated the performance of MyMANET in real traffic with different topologies. We used an indoor testbed at the Klaus Advanced Computing building at Georgia Tech, with various node positions (P1 to P10) as show in Figure 5. We decided to use Ubuntu operating system for the testbed because of ease of package installation and dependency resolution. More precisely, we varied the following aspects:

1. Topology: We consider two topologies, namely (a) *diamond* (for e.g. P3-P4-P5-P6) and (b) *path* (for e.g. P3-P5-P6-P8).

2. Traffic: We generate traffic for periods of time, by varying both the number of pairs communicating and the amount of traffic for each pair.

3. Mobility pattern: We use two different mobility patterns. In the first, a single mobile node moves from one end of a network to another while maintaining communication with one of the other nodes. In the second, multiple nodes move randomly sometimes going out of range of the network.

We believe that for a solution like MyMANET to be useful in networks like MANETs having a high degree of transience, the following charecteristics will be required. The platform should be stable, scalable and the processing overhead should be minimal. Adding more nodes should improve the network performance and connectivity should be maintained for an extended period of time in presence of high-volume network traffic. The platform should support densely connected MANETs with high mobility, as well as sparsely connected ones having large inter-node distances. The performance of MyMANET is evaluated using three metrics: connectivity, packet


Figure 5: Placement of nodes in the testbed

loss and throughput. We also track the virtual distance computed by the routing protocol to see how it correlates with the other parameters.

**Stable connectivity.** In the first experiment, we used four static nodes (P3-P4-P7-P8) with one pair of nodes (P3-P8) communicating in a path topology. Moreover, the end nodes at P3 and P8 were far enough apart that they did not have direct connectivity. The packet loss was zero in spite of multi-hop transmission. The Figure 6 shows

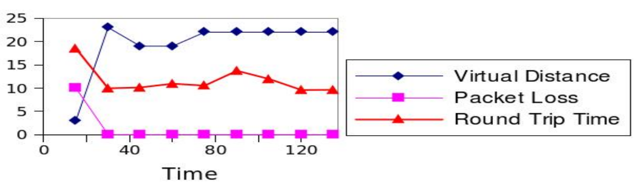


Figure 6: RTT, packet loss and virtual distance over time

that these parameters remain relatively stable. We ran file transfer utilities on top of the MyMANET platform and observed that it's quite stable and files could be transfered reliably between a pair of nodes which did not share a direct link.

**Multi-path routing and its benefits.** In this experiment, we used node *A* at position P3, *B* at P6, *C* at P4 and *D* at P5. We started communication between *A* and *B* ($E1$), then added two more nodes *C* and *D* to the network ($E2$) to form a diamond topology; then initiated communication between *C* and *D* ($E3$), then *A* and *B* stopped their communication ($E4$) and finally all nodes came off the network($E5$). As we see in Figure 7, adding more nodes to the network *improved* the end-to-end parameters and multiple communicating pairs were able to share the network.

**Scalability.** Here we measure the scaling properties with respect to distance and traffic.

First we see the effect of increasing traffic. The nodes *A*, *B*, *C* and *D* were placed at P11, P3, P4 and P7 respectively. As is evident, nodes *A* and *B* were separated from each other by two walls and a greater physical distance than other two nodes. We incrementally increased the net traffic by adding communicating pairs *A*-*B* at event $E1$, *A*-*C* at $E2$, *A*-*D* at $E3$. Then, we reduced the net traffic by terminating communication between *A*-*B* at $E4$, *A*-*C* at $E5$ and *A*-*D* at $E6$. Figure 8 depicts that the average packet loss of the entire network deviated by +/-20%.

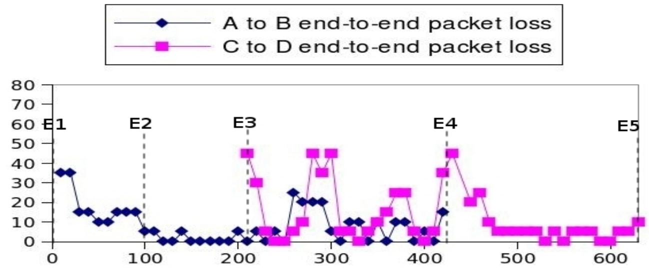


Figure 7: Effect of multi-path routing on the observed packet loss

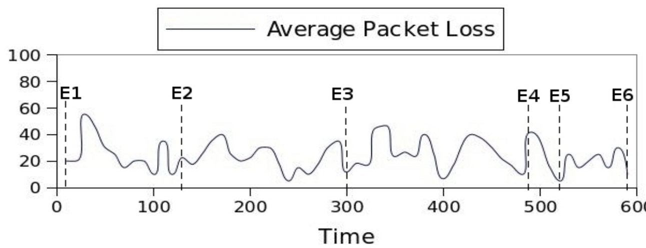


Figure 8: Effect of increase in number of communicating pairs on the observed packet loss

Next we turn to the performance when we increase the physical distance between adjacent nodes of the network. Note that the diameter of the network was 3 times larger. Figure 9 also shows that the virtual distance closely follows the packet loss, even though updates have to be propagated through the network. This makes it a viable metric for dynamic routing.

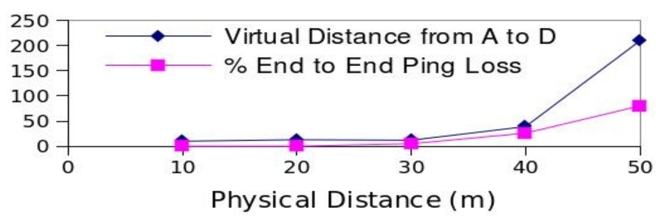


Figure 9: Effect of increasing physical distance on virtual distance and end-to-end packet loss

**Mobility.** We used one mobile node *M*, to communicate with one out of 3 other fixed nodes at P3, P6 and P9 arranged in a line topology. The mobile node *M* was initially situated near P9, gradually moving away from it; and then again coming near this node after completing a full cycle (P9-P8-P5-P2-P4-P7-P8-P9). The Figure 10 clearly shows the direct correlation between mobility and the observed packet loss. We extended the aforementioned experiment with 4 mobile nodes communicating in pairs in a similar, but larger indoor set-up. It was observed that in spite of wireless interference, mobility and obstructions like Walls; there was seamless network connectivity.

## 5 Related work

MyMANET is motivated by some of the conceptual ideas in [18], namely incorporating asymmetry and obstacles without explicitly modeling the network. However, our realization of these ideas is quite different and appears much more practical. In this section,

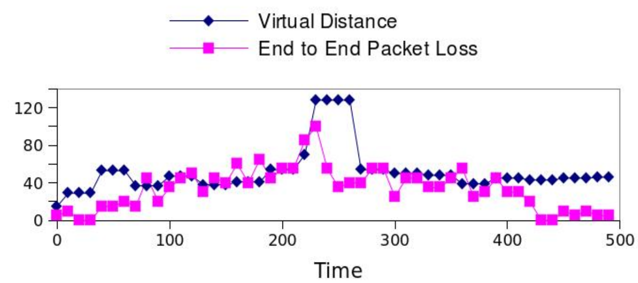


Figure 10: Plot of packet loss vs time as one node M moves around all other nodes (fixed) and communicates with a fixed node at P9

we discuss three bodies of related work: wireless connectivity in developing regions, platforms for wireless experiments and wireless routing protocols.

**Wireless connectivity in developing regions.** Projects in the research community aimed at solving connectivity issues in developing regions include DUMBO [19], Fractel [26] and WiLDNet [24] (see also [1]). The DUMBO project [19] is a multimedia communication system for collaborative emergency response operation in disaster-affected areas. Fractel and WiLDNet demonstrate that long distance wireless links based on directional antennas (among other things) are a cost-effective and reliable alternative to traditional connectivity solutions especially in rural settings. Unlike in previous observations [16], these systems are able to realize nearly zero error rates due to the lack of external interference. Our work compliments these research efforts by providing a robust and cost effective *extension* and *distribution mechanism* within a relatively small geographic area using these long distance connection points. Moreover, MyMANET does not rely on any infrastructure such as towers or specialized antennas, making it easy and quick to deploy. On the other hand, since it could support a high density of users, the system needs to be able to handle a variety of traffic and interference patterns, quite different from those of long-distance wireless links.

**Platforms.** These fall under two types: testbeds and portable platforms. The distinguishing feature is that testbeds are usually physically localized (in a room or on a campus or in parts of a town), typically with fixed nodes. We begin with related work on portable platforms.

The Click modular router [20] provides a software architecture for building configurable routers. Grid [22] is a system for routing in wireless ad hoc networks implemented in Click. Unlike Click, MyMANET is based on a WDL (Layer 2.5) approach which, we believe, is a more effective solution for wireless networks than solutions that rely on maintaining routes and/or topology explicitly. MyMANET packets themselves contain routing/control information which helps make forwarding decisions efficiently. FlexMAC [30] is another type of platform that supports variation at the link layer using specialized drivers. Although MyMANET does not support variation at the link layer, it is more generic as it is independent of the type/make of the wireless card used. It uses the standard 802.11 link layer, the default protocol with most commodity hardware available today. Thus, unlike FlexMAC, MyMANET can be used on any laptop running Linux without making any driver modifications. This aspect seems particularly important for sustainability in developing regions.

We next discuss testbeds for wireless networks. The OneLab testbed is intended to extend the overlay network capabilities provided by PlanetLab [10] to wireless networks. Roofnet [16] is based on Click, but does not allow mesh clients to participate in routing. This results in mobility restrictions and requires dedicated Roofnet routers. Microsoft's Mesh Connectivity Layer(MCL) [28] is a Layer 2.5 virtual network driver that facilitates formation of a community mesh network. These and other testbeds [3, 4, 12, 14, 23, 29, 32] provide a platform for wireless mesh networks. They are based on infrastructure nodes and low to zero mobility, as opposed to MANETs, one of whose principles is a network based on user nodes alone with no infrastructure nodes.

**Routing.** Wireless routing algorithms fall into two broad categories: proactive and reactive. The Pro-active protocols like [5, 7, 8, 31], maintain routing paths by periodically distributing routing tables and probing the network continuously. Reactive protocols like [15, 25], probe the network in response to a request, build a path and use it. Some other routing protocols like [9, 13, 21, 27, 34], can neither be classified as pro-active nor reactive; and are designed with specific objectives. Based on the method used to calculate the optimal path, all the routing methodologies are further classified into *Link state* and *Distance Vector* classes.

In all the aforementioned cases, the protocol has to maintain or build a representation of the network, just as wired protocols do. Unfortunately, the highly transient nature of wireless links makes this rather impractical and we believe this is the reason why robust implementations of such protocols are not available and the ones that are available are restricted to mesh networks or even more specialized.

ExOR [6] is specifically designed for increasing throughput of large unicast multi-hop transfers. MyMANET is based on the ideas of cooperative diversity and broadcast transmissions also used in the ExOR protocol. However, unlike ExOR, MyMANET does not maintain any explicit representation and does not need probing with a burst of packets. ExOR was prototyped on Roofnet [16] and is believed to be the media access protocol in the Meraki wireless mesh network [33]. In Meraki, routing is primarily done to route to the nearest gateway. Unlike MyMANET nodes, Meraki clients do not have direct access to each other. MyMANET combines end-to-end measurements with distance-based routing without using any explicit representation.

## 6 Discussion : Paths to Deployment

We have implemented MyMANET as an open-source platform on commodity hardware with our default routing protocol. Our evaluation suggests that it is stable, customizable, scalable and robust to traffic variation and mobility. MyMANET can readily support any distance vector routing protocol and extending it to support other kinds of protocols like Dynamic Source Routing (DSR) should not be difficult.

It is our hope that such a reliable and low-cost multi-hop wireless network that leverages existing wireless mobile devices, can help in increasing access in developing regions as well as in response to emergencies. We now discuss two paths to deployment in detail.

**Local traffic and 'last-mile' Internet delivery.** With the capability of self-organization and self-configuration, MyMANET nodes can be deployed incrementally, one node at a time, as needed. There are several important tasks that can be accomplished *without* using the Internet (i.e. local traffic). As an illustration, consider an event distribution server that sends updates specific to a local area/Village. These updates can range from being as generic as weather updates and crime alerts; or can be as specific as a monthly power bill. Medical information systems, agriculture, VoIP solutions, can be useful if deployed in villages. Emergency relief operations generally rely on radios that have limited range and are essentially single-hop. Unlike radios, MyMANET nodes can be set up quickly and are scalable. MyMANET's multi-path forwarding protocol allows communication with weak individual links and this could be useful for disaster management and emergency relief operations.

In areas where Internet is available (using satellite links, etc.), people can cost-effectively share Internet access with multiple users.

A MyMANET node having internet connectivity can be configured as an Internet Gateway. The gateway node can advertise itself using heart-beat packets (used by the GNSM). The WDL at each node (packet originator and intermediate nodes) would route internet packets to the nearest MyMANET gateway-node. Thus, the WDL will select the MyMANET gateway with the least virtual distance. A MyMANET gateway will have internet access through one interface and provide internet access to other nodes using its other (wireless) interface configured in Ad Hoc mode. Note that local traffic would still be routed using the default routing protocol.

**Urban Wireless Networks.** We now discuss the deployment of MyMANET in an Urban scenario. Research has shown that traffic in public wireless networks is mostly transient and bursty [11]. When traffic is sent sporadically, the previously constructed routes by conventional ad hoc routing protocols are hardly ever re-used [11]. Consequently, transient traffic will lead to generation of route discoveries much more frequently. For a high data rate traffic, data packets will interfere with the control packets, leading to significant decrease in performance[11]. We believe that MyMANET, being robust to traffic variation and mobility can be particularly useful is such a scenario. Several users in a city block can install MyMANET and run the module using a user-friendly start-up script provided by MyMANET. In order to be effective in such a setting and for such a user population, MyMANET would have to be easy to configure and set-up, manage and troubleshoot. We plan to make all these aspects user friendly; for e.g. installing the module will be a single click. MyMANET enables each and every node to get a global view of the resources as well as all the link qualities of the network. We will add a web-based user interface for this global view to aid in network management and troubleshooting.

We plan to port MyMANET code on Linux-based wireless dongles. These dongles can be plugged into any commodity PC through USB drives. This can help users with Windows or MAC machines run MyMANET with little effort. Apart from end-point devices, embedded low-power routers can use MyMANET. These tiny and inexpensive MyMANET nodes can be deployed to increase connectivity and provide greater access. We are collaborating with the TeNet Group [2] in India to test and deploy MyMANET in a busy neighbourhood of Chennai. Such partnerships could lead to products that are more affordable and better suited to the requirements of developing regions.

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