Improving the Stability of Transmission in Mobile Ad Hoc Networks

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Abstract. Protocol development in Mobile Ad hoc NETworks (MANET) has been a hot topic for many years, yet the performance exhibited from recent deployments [1] is still not optimal and not suitable for large scale practical use. Stability of transmission is a critical aspect in mobile ad hoc networks, as by improving the stability of end-to-end transmission, the network could deliver more consistent service and achieve efficiency gains. We propose a protocol architecture which aims to improve the stability of transmission inside MANET using limited additional information based on the location of wireless nodes. The draft architecture and the initial progress in this project are also presented in this paper.

Key words: MANET, Stability, Location, FPGA

1 Introduction

Mobile ad hoc networks are a combination of mobile terminal nodes equipped with wireless network capability that does not rely on additional infrastructure (e.g. base station, access point) to operate. This flexibility makes ad hoc networks suitable for scenarios such as disaster recovery e.g. in an earthquake scenario where the existing infrastructure is knocked out. Nodes in ad hoc networks need to act as routers when they are on the path between distant node pairs that cannot reach each other directly. This greatly increased the complexity and transmission cost for packet transmission in ad hoc networks and raise more challenges compared to cellular wireless networks. MANET nodes need to provide some quality of service to their neighbourhood if we are to enable effective end-to-end transmission, especially for real time traffic such as voice. With over a decade of research in this field, the current ad hoc protocols still have some key problems that prevent them from true success. One critical problem is the reliability of transmission in ad hoc network, which is affected for example by routing stability, node mobility, miss-behaviour of protocols at different layers of the stack and more.

Our research is focused on improving the stability of transmission in MANETs, as by improving stability we could deliver more consistent service for an end-to-end transmission and improve the overall efficiency of the system by reducing the overhead of retransmissions. We will present the draft proposal of a multi-layer architecture that makes use of node location information that should improve the stability of ad hoc transmission. The proposed architecture includes a neighbourhood aware MAC, a location aided routing protocol through transport protocols such as the SCTP (Stream Control Transmission Protocol) with cross-layer functionality extensions. We are also looking into network feedback mechanisms and protection mechanisms to reduce the network costs when certain end-to-end and link connectivity feedback is lost during packet transmission.

This paper is organized as follows: In Section 2, we analyse the MANET stability problem. Then, we in Section 3 we introduce some details of the proposed protocols in our architecture. We present our progress and future plan for our project in Section 4.

2 Problems in Ad Hoc Networks

The experiments conducted by MobileMAN [1] have shown that the instability of transmission is one of the major causes of the performance degradation in their mobile ad hoc environments. In this section we identify some of the causes of the instability in MANET and analyse some possible solutions to reduce this instability.

2.1 Cause of Instability

The root of instability lies in the dynamic nature of the MANET, which are caused by the mobility of nodes and the change in wireless link characteristics. Links between nodes change when nodes move. When nodes move away from each other, the link quality drops and eventually the link breaks when the pair is out of transmission range of each other. As we cannot limit the movement of the nodes inside the network, what we can do is to estimate when the link between a pair of nodes is likely to break. To perform such a prediction inside the network, we need additional information to be transmitted or shared by the nodes.

We are investigating using the location information of the nodes in MANET to predict node connectivity in order to minimise network instability. Location information can be obtained for example from GPS, time of transmission techniques or received signal strength techniques. GPS provides a good self contained modular solution for location information with its accuracy depended on satellite visibility. Time of flight method somehow requires access to a high accuracy clock at sender and receiver, the clock accuracy and triangulation determines the location of the sender. Received signal strength technique are the most ubiquitous but suffers from uncertainty in location as the signal strength varies with many factors. Low overhead is required to transmit location information around the network, and by having location information we could predict a node's future movement using historical data. This information could then be used at a number of protocol stacks in order to increase network stability as discussed in section 3 (e.g. at the MAC layer and the network layer in the routing protocol).

The second cause of instability can be classified as the over-reaction of protocols to various network events. Wireless ad hoc protocols, in general, can only judge the network status from various feedback mechanisms such as MAC beacon frames, ACK frames and TCP ACK packets. If this critical feedback is lost, the protocol will assume that there is a problem in the network and perform recovery even when the cause is not rooted in the network. The protocol layer in isolation doesn't necessarily have enough information to judge the end-to-end conditions on the loss event that it detects, the provision of messages from other protocol layers could help the protocol to judge the cause of the event and perform more effective actions at the protocol layer. The provision of feedback messages from other layers of the protocol stack has been investigated in a number research projects like the Explicit Link Failure Notification (ELFN) [2] which provide information from network layer to transport layer to help TCP in ad hoc environments.

An alternative way of reducing the effect of instability is to provide protection on the critical transmission components, optimizing network feedback, and reducing loss. We aim to investigate some enhancements to the feedback behaviour of some of the protocols in our system to test this approach. We expect to use multiple feedback which has been investigated by Greensten et. al at [3] or standard feedback mechanisms plus additional piggy back data in our system.

3 Proposed Solutions

More details of our proposed system are presented in this section, including new protocols at different layers, enhancements on existing protocols and effective messaging architecture between protocol layers.

3.1 The Implementation Platform

WAG Platform WAG stands for Wireless Analysis and Generation. It is a wireless protocol experiment platform developed by the WAND [4] research group of Computer Science Department at the University of Waikato. WAG is a complete system with a wireless NIC (Network Interface Card) using FPGA, a Soekris Engineering [5] x86 based compact computer and an embedded Linux OS with drivers, protocol implements and measurement tools. We have used this platform as the initial basis of the protocol development in our project.

The wireless NIC is the major component in the system. It is equipped with a Xilinx FPGA, 802.11b radio and modem, on-board RAM and PCI and serial interface. By using an FPGA, we have the flexibility of implementing any MAC protocol here, not just limited to IEEE 802.11. In addition, we can put functions

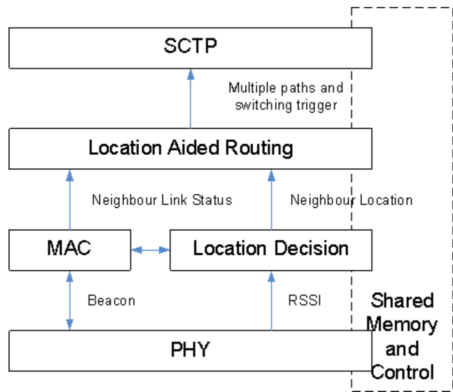

Fig. 1. Controlling Flow of the Proposed System

(e.g. local table management, node separation prediction) inside the FPGA to take advantage of fast calculation and close integration with the MAC protocol.

There are also development tools available which translate the system level design in SDL (Specification and Description Language) into C/C++ codes that could run on FPGA. A simulation framework also exists that allows the use of the C/C++ code directly in the NS2 network simulator.

Cross-layer Architecture A specific header is used to exchange information (frame size, receiver parameters, etc.) between the FPGA and device driver in the current WAG framework. It is 32-byte long and not large enough to carrying neighbourhood information in our project. Two cross-layer messaging methods will be evaluated on the platform before deciding on the architecture. One method is using a shared memory space for these informations which is similar to the architecture proposed in MobileMAN project [6] . Another method is to introduce special types of management packets between device driver and the MAC, which carry these information around the protocol stacks driven by different events.

MADWifi Platform MADWifi or Multi-band Atheros Driver for Wi-fi [7], is a set of Linux device drivers developed for wireless LAN cards using the Atheros chips. The unique feature of this driver is its ability of controlling some of the hardware functionality via HAL (Hardware Abstraction Layer, a binary interface provided by Atheros). This ability makes the MADWifi platform a possible alternative protocol implementation platform for our proposed system. We are still looking at the platform and evaluating this possibility which promise to be more cost effective but not as flexible at the MAC layer.

3.2 Neighbourhood Aware MAC

This MAC protocol is a simplified contention MAC based on similar resolution mechanism that we used in the DCF (Distributed Coordination Function) in the

IEEE 802.11 standard [8]. The novel element in this MAC is the neighbourhood management function. This function is composed of three parts: neighbourhood detection, neighbourhood information management and neighbourhood information exchange.

The neighbourhood of a node is detected via a listening unit attached to the receiving block in the MAC. It processes all frames received by the node and tries to extract as much information from these frames as possible, e.g. source MAC address, source IP address, RSSI of the frame, etc. All this information will then be passed to the neighbour information management unit, which is basically a table management function. We have three tables related to neighbour information inside the MAC, one for neighbourhood link, one for neighbourhood location and one for on-going TCP/UDP flows on each neighbour. The management function is in charge of inserting new entry or update existing entry using the information from the hearing unit, deleting stale entries after they are kept for certain time and responding to queuing request from MAC or other layers. The last unit, is the information exchange unit. It is the most complex part in the neighbourhood function. It controls the exchange of the three tables among a node's one-hop neighbourhood, enabling some important functions in the system. We will use a MAC beacon frame to carry these tables, however, as the size of the tables grows (location table will include some previous location information for mobility prediction), it is not efficient to broadcast these big frames frequently. On the other hand, we need fresh location information carried by the beacon to perform mobility prediction for the neighbourhood. To balance between the overhead caused by the exchange and the requirement of timely update, we propose an adaptation algorithm that controls the interval and content of each beacon. This algorithm takes feedbacks from mobility prediction and table management units to obtain a view of network situation in the neighbourhood area. It then selects different intervals for each table according to the calculation from this feedback, and manages the beacon mechanism accordingly.

An algorithm of judging node's location using different techniques (GPS plus received RSSI of different nodes) will be introduced to the data link layer. We will test several algorithms from [9] and [10] and the system developed at Victoria University [11] [12] to check whether they could operate in our environment. A few nodes with existing knowledge of their location will act as the reference nodes inside the network, and other nodes will calculate their relative location from these reference nodes to obtain a geographical view of the network. Also we will implement the enhancement of contention resolution proposed in the paper by Durvy and Thiran [13] in this MAC to improve its performance.

3.3 Location Aided Routing

Geographical or location based routing protocols use node location information to help the routing process. Based on how location information affects the routing process, we divide location based routing into two sub categories: location routing and location aided routing. Location routing protocols like [14] use only location of nodes to perform the end-to-end transmission without having an end-to-end path while location aided routing protocols like "dream" [15] use location information together with other metrics (hop count, etc.) to help reduce the overhead or increase the speed in finding new routes. We need the end-to-end view of the path to perform some operations (e.g. switching) thus we need a location aided protocol in our system.

We will use proactive routing in this project for two major reasons: first, we are going to introduce transport layer switching in this project, and proactive routing is more efficient as it should have many routes available at any one time. Second, we need a method to spread the three tables from the neighbourhood function throughout the network to obtain an overall view of the network which then could aid end-to-end routing and transport protocols. This could be done together with the exchange of routing information and saves the effort of developing a separate function. There are two main concerns in this protocol, how to select the route and how to exchange routing information (and the tables) with proper costs.

As discussed in the previous section, we need a long lasting route between source and destination to improve the stability of the transmission between the pair of nodes. This is achieved by selecting the route that has the longest estimated existence time between the end-to-end pair. This end-to-end estimation comes from the calculation of all one-hop link existing time along the path using local prediction values inside the location tables. One problem with this decision algorithm is that it tends to select the links between fixed nodes or nodes with stable links, which might cause bottlenecks in the network. In order to overcome this we decided to add more elements in the routing decision metrics to help satisfy route requirement while maintain certain level of fairness among on-going sections in the network. These elements includes: path collision status, traffic requirement, path length and geographical topology information.

Some of the critical elements identified in several protocols are also obtained from the global picture formed from local tables. How to effectively exchange these tables in the network is the next issue to be determined. Here we propose an algorithm that combines the flooding and remote queuing (push and pull). In the initial stage, nodes will flood the tables to the network to form the overall network picture. Then nodes will try to queue and process tables from other nodes in the neighbourhood which will update the nodes information of that area and prevent its state becoming stale. The queuing consequence is similar to the route discovery process in reactive routing with geographical constraints.

3.4 Other Protocol Stack Aspects

Two specific protocol stack aspects will be discussed in order to complete our introduction to stability in MANETs. These are developments in transport protocols and in cross layer feedback mechanisms. One of the key developments in transport protocols is a message oriented protocol called SCTP which can be used in MANETs in order to switch between streams. Secondly feedback mechanisms can be envisaged between protocol layers in order to reduce protocol sensitivity.

SCTP The Stream Control Transmission Protocol (SCTP) [16] is a reliable transport protocol originally designed for telephony signalling. It is a connection oriented protocol much like TCP and also borrowing some beneficial features from UDP. The most interesting feature of this protocol to us is multi-homing, which allows the end-to-end pair to establish multiple paths using different interfaces and switch to alternative path if one path fails. SCTP will be introduced in transport layer in our system to provide protection on end-to-end transmission via switching between two alternative paths, the switching would take effect on a link outage event, or quality impairment on the primary path.

Some modifications will be done on SCTP to make it work better in our system. SCTP will try to switch between disjoint paths on the same wireless interface now and the status of selected paths will be maintained by routing protocol instead of the heartbeat packets in the SCTP proposal.

Also some enhancements for wireless environment will also be implemented, e.g. the Explicit Link Failure Notification (ELFN) for TCP could also be implemented, as SCTP uses identical congestion control method as TCP and the enhancement proposed by Fracchia et. al at [17].

Feedback Mechanism To reduce the over reaction of the protocol, we can introduce feedback information from different protocols (such as the ELFN mentioned before) which could help to gain a better understanding of what is actually happening in the network. We can also tweak the parameters of the protocol as defined by the MobileMAN project [1] to reach a balance point of sensitivity.

We will also look into the protection methods for the critical feedbacks in order to minimize the cost of loss of these feedbacks. One possible solution is the packet salvation proposed by Yu, Shin and Song [18], where neighbourhood nodes hear the feedback could help to reproduce the feedback if it is lost at the destination. One other way is using redundant/multiple packets for critical feedbacks like in [3], and we can piggyback these feedbacks to data or other packets to reduce the chance of collision.

4 Current Progress and Future Plans

We are working on the detail proposal of each protocol inside the system and also collaborating with WAND workgroup at the University of Waikato on the WAG hardware platform. We are also investigating the possibility of the alternative implementation platform of MADWifi now. We plan to implement the multi-layer architecture in the NS2 network simulator and verify its functionality. Then this system will be implemented using the WAG platform or MADWifi and tested in a real world test-bed.

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