Routing in Mobile Phone Ad Hoc Networks

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Abstract—The advancement of mobile phones is creating cheaper and more powerful devices that are capable of providing networking services using readily available technologies embedded on mobile phones. Networking services are usually provided using fixed cellular infrastructure owned by Cellular Network Providers. The use of the cellular infrastructure incurs the cost of data exchange. One way to eliminate costs is to create spontaneous ad hoc networks that allow mobile phone users to connect directly and share information using technologies such as Bluetooth. In order to efficiently share information, routing techniques are needed that efficiently use the resources in these networks. This paper presents the design of a mobile phone ad hoc network and a prototype system that uses established routing algorithms to determine which routing protocols are well suited for such a network.

Keywords-mobile ad hoc network; routing; Bluetooth;

I. INTRODUCTION

Mobile phones are equipped with many networking technologies such as Bluetooth, WiFi, Infrared. In 2010, 906 million Bluetooth-enabled mobile phones were shipped worldwide [1]. This figure attests to Bluetooth's popularity. Bluetooth is an intuitive, point-to-point data exchange protocol which incurs no extra costs when exchanging data between mobile phone users, unlike Cellular Network Providers who charge for data exchange. The research uses Bluetooth connectivity between mobile phones to build spontaneous ad hoc networks that allow mobile phones to exchange data in a multihop manner. To aid information exchange, efficient routing techniques need to be investigated. The paper discusses the results obtained from implementing existing routing protocols used in mobile ad hoc networks (or MANETs) in spontaneous ad hoc networks consisting of mobile phones connected via Bluetooth. Mobile phones have limited processing power, battery life and storage. Routing protocols should wisely use these limited resources while at the same time be able to deal with unpredictable behaviour [2] caused by mobile phones being switched off or moving out of communication range with other devices, for example.

The paper is organized as follows: Section II presents related work on routing in mobile ad hoc networks, routing based on content, and routing in networks that use Bluetooth connectivity. In Section III, discusses how the mobile phone ad hoc network is formed and the design of the routing protocols implemented. Section IV discusses the implementation of a mobile application that allows mobile phones to form an ad hoc network. Section V, discusses the evaluation of the system. The paper concludes with a comparison of the results obtained from the implementation of the routing protocols.

II. RELATED WORK

Routing is a challenging research area in mobile ad hoc networks (MANETs). Devices in MANETs with limited resources and are highly mobile create highly dynamic network topologies which affect routing performance. High dynamicity can cause data loss in the network, waste limited mobile device resources such as battery power, and cause high communication overhead in the routing protocols. MANET research has been dealing with this problem and has come up with routing protocols to reduce these costs. On-demand routing protocols developed such as Advanced On-demand or source-initiated Distance Vector Routing (AODV) and Dynamic Source Routing (DSR) discover routes when they are needed. As a result, they incur little communication overhead resulting in minimal data loss during disconnections between mobile devices. These protocols allow a mobile device to make its own routing decisions whenever it needs to send information [3][4]. These protocols allow the routing decision process by initiating two routing mechanisms: route discovery and route maintenance. The route discovery process finds neighbouring device addresses within communication range. Route maintenance maintains the routes discovered earlier and initiates route re-discovery if links are broken. AODV differs from DSR in that DSR does not initiate periodic route maintenance as AODV does.

Contrary to source-initiated routing protocols, content-based routing protocols used in publish/subscribe networks also seem well suited to disseminate information in dynamic mobile ad hoc networks [22]. A content-based routing algorithm forwards information based content, not the destination address as required in AODV and DSR. Content-based routing provides asynchronous communi-
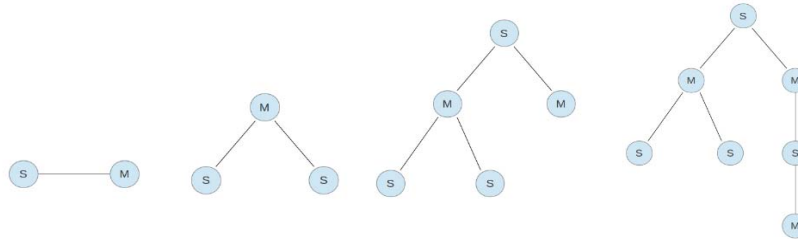
Figure 1. Networks formed. *M* = master device; *S* = slave device

cation in decoupled networks. Decoupling means that devices or nodes in the network do not know each other, and asynchrony shows that nodes do not need be connected at the same time to exchange information. Due to these characteristics, the publish/subscribe paradigm is well suited to communicating with nodes in MANETs that require the exchange of information in an opportunistic manner.

Routing in Bluetooth ad hoc networks also known as scatternets uses several techniques: *cross-layer optimizations* align the Bluetooth data link layer and network layer, hoping to incur little control overhead during communication [5]. Liu et. al [6] implemented s*catternet formation* apart from routing to discover and form multihop routes using the master-slave restrictions imposed by the Bluetooth protocol. The scatternet formation technique is on-demand, only forming routes when needed. This way, the scatternet formation mechanism consumes less battery energy. Huang et. al [7] adapted AODV for Bluetooth using cross-layer optimization which assigns a load metric to the link between connected Bluetooth devices. Periodic HELLO packets are sent between the data link and network layers to assess link status.

Other scatternet formation algorithms such as that used by Tan et. al [8] create a scatternet with a tree-like structure between master/slave devices. Their tree-structure formation algorithm reduces scatternet formation latency.

A technique inherent in most routing protocols like AODV and DSR to establish initial routes between devices is broadcasting. AODV and DSR use broadcasting for initial route discovery [23]. Each device sends a message to its neighbouring devices to establish routes and may typically send several messages to maintain these routes. The main problem with broadcasting is that causes congestion. There are however research efforts to improve broadcasting efficiency.

III.   SYSTEM DESIGN

The formation of the Bluetooth ad hoc network and the routing protocols implemented are discussed in this section.

A.   *Network Formation*

According to the Bluetooth protocol specification, devices establish a master-slave relationship. A device with the master role maintains communication with a maximum of seven other devices in slave mode. A multi-hop network is created by placing alternate master-slave devices in the network as shown with the network topologies in Figure 1.

B.   *Routing*

The following routing protocols were implemented in the networks indicated in Figure 1 [24]:

1) Broadcasting: Broadcasting forwards a message initiated by a device (called an initiator) to all connected neighbours of the initiating node. Once a message is received at the receiving devices, it is forwarded again if it was never seen before; otherwise it is discarded [10], [11] with the assumption that it is a duplicate message.

2) Advanced On-demand Distance Vector Routing (AODV): AODV is implemented based on the draft specifications of the Internet Engineering Task Force (IETF) [12]. Route discovery and route maintenance are implemented for this protocol. AODV maintains routing tables with route information indexed by unique sequence numbers to distinguish routes. AODV periodically updates these routes using the route maintenance function.

3) Dynamic Source Routing (DSR): DSR is also implemented according to specifications of the IETF and it initiates route discovery only when a node needs to forward data in the network [13]. DSR does not do route
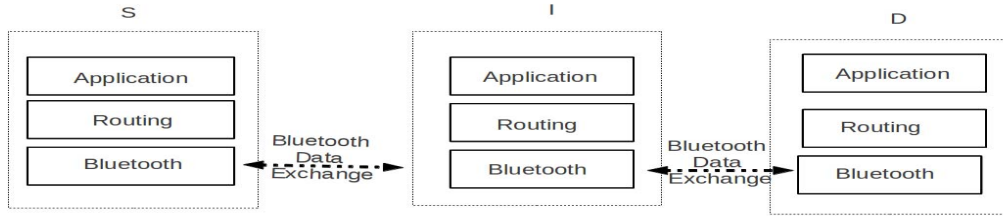
Figure 2. Prototype implementation layers. S = source device; I = intermediate device; D = destination device

maintenance, i.e. the protocol does not permit a device to send out periodic route advertising or link status sensing messages to neighbouring devices [3][14][15].

4) Content-based Routing: Using concepts adapted from various research ([16], [17], [18], [19], [20], [21]), the network allows a device to send information throughout the network depending on the type of content that was originally requested by an initiating device.

IV. SYSTEM IMPLEMENTATION

A prototype was developed that consists of 3 implementation layers as shown in Figure 2. the prototype is deployed on mobile phones and allows them to form a mobile ad hoc network.

V. EVALUATION

A. Experiment Setup

Emulation was used in a controlled environment to simulate network formation and users requesting information entered at the Application layer shown in Figure 2. The controlled environment provided comparable results through availability of links between devices. Real world experiments with users raised some challenges which emulation easily overcame. Availability of connections between devices was volatile in real world testing but with emulation, connections were available to test the efficiency of the routing protocols. Emulation therefore allowed for the behaviour of the prototype to be observed closely. Figure 3 shows how emulators labeled as nodes forward a data request from Node A to Node C.

B. Performance Metrics

The following performance metrics we chosen to determine how effectively the routing protocols perform in the topologies shown in Figure 1.
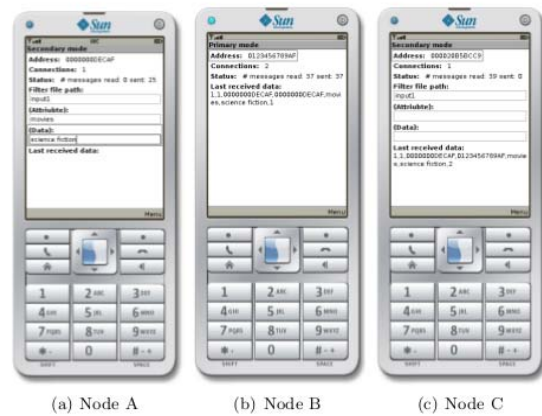

(a) Node A   (b) Node B   (c) Node C

Figure 3. Emulators forwarding a data request

1) Total traffic: Total traffic, T_T, is the number of messages, *msg*, that pass through an active link and received at each node. Traffic includes periodic update messages, route requests, route replies, route error messages, data requests, data replies and data error packets. Total traffic is measured in bytes and can be used to interpret how much power will be used in the network by the mobile phone devices. Total traffic is calculated as follows:
$$T_T = \sum(msg*packet\_size)$$
The metric shows how the increase in network size and number of messages affects the network. This is an important metric, for example, it can be used to deduce the duration or battery lifetime of mobile phones(perhaps also indicate users' willingness to use the application) [24].

2) Data traffic: Data traffic, T_D, is the number of successfully received data requests excluding control messages, *msg*, measured in bytes, received at each node. Data traffic is represented as follows:
$$T_T = \sum(msg*packet\_size)$$
The metric determines the effectiveness of the routing protocols in delivering data packets [24].

3) Control traffic: Control traffic, T_C, is the difference between total traffic, T_T, and data traffic, T_D, in the entire network. Control traffics includes all route discovery and route maintenance messages.

$$T_C = T_T - T_D$$

The metric determines how much traffic is due to control messages, and which routing protocols transmit more data with as little control traffic as possible [24].

4) Average Delay: Average Delay, D_T, is the average amount of time between when a message is sent from a source device and received at a destination device, including processing delay. The metric determines which routing protocol transmits messages faster through the described network [24].

5) Convergence Time: This metric, C, is the time taken to establish a stable network topology. Convergence time is determined by measuring the time difference between sending the first route request at a source device and receiving the last route reply at the source device. That is:

$$C = t_{recv} - t_{sent}$$

The shows how quickly a network adapts to changes [24].

6) Positive Response: The positive response, PR, is the number of data replies, $rmsg_{recv}$, successfully received by a requesting device compared to the number of data requests, $dmsg_{sent}$, it sent out:

$$PR = (rmsg_{recv} / dmsg_{sent})*100$$

The metric determines how well the routing protocols respond to data requests [24].

C. Message Generation

Messages exchanged during initial route discovery for all routing protocols start with a route request message initiated by a source device or node. A route request is answered with a route reply by devices that received the route request. During communication, a participating device initiates a data request and awaits either a data reply, data reply error or route error when a link is broken. To collect, data transmission is emulated with twenty trial runs. During each trial run, a random node generates fifty random data requests which are transmitted throughout the network [24].

D. Results

A comparison of the performance metric results is given in this section.

1) Total traffic: As seen in Figure 4, Broadcasting, AODV and DSR total traffic increased significantly as the network size increased. On the other hand, Content-based routing total traffic increased gradually as the network size increased.
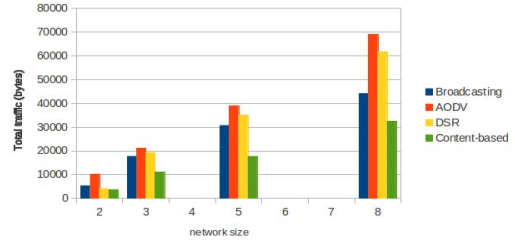

Figure 4. Total traffic vs. network size

2) Data traffic: Figure 5 shows that as the network size increased, AODV, DSR and Broadcasting data traffic increased significantly compared to Content-based Routing. Data traffic increased gradually for Content-based routing as the network size increased. Again, the design decision to have devices transmit data to their one-hop neighbour and not propagate requests throughout the entire network, like Broadcasting, reduced the growth of data traffic. Broadcasting also generates more data traffic because it simply forwards data requests to all connected neighbouring devices. On the other hand, AODV and DSR decide where to send the data request but the increase in data traffic is due to the use of the configurable time-to-live counter which determines the how many times the message is forwarded if it is unanswered.
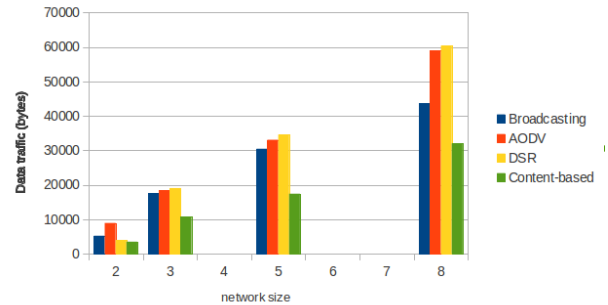

Figure 5. Data traffic vs. network size

3) Control traffic: The control traffic incurred by AODV increases significantly as the network size increased as shown in Figure 6. AODV has more control traffic because of the route maintenance process initiated periodically. However, DSR control traffic remains significantly less than AODV because control packets are not generated periodically. Control traffic for Broadcasting and Content-based Routing was also significant less than AODV and DSR because these protocols only generate control packets via the route discovery process which is initiated at the very beginning at network setup. No route

maintenance was initiated either. In summary, AODV has a significant amount of control traffic as a result of control packets generated during route discovery and route maintenance.
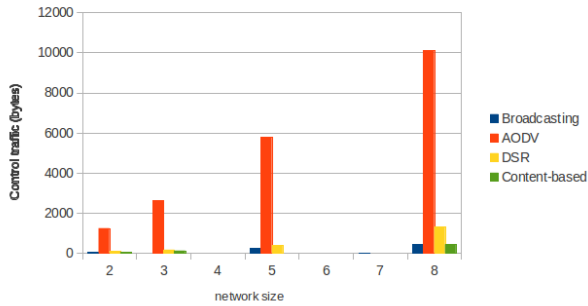

Figure 6. Control traffic vs. network size

4) Average Delay: Figure 7 shows AODV and DSR average delay increased as network size increased. Broadcasting and Content-based Routing show a decrease in delay as network size increased. Shorter delays were observed for Broadcasting and Content-based routing because there is little processing delay at the nodes, and messages traverse multiple paths to reach the desired destination unlike AODV and DSR which decide along which path to send a message.
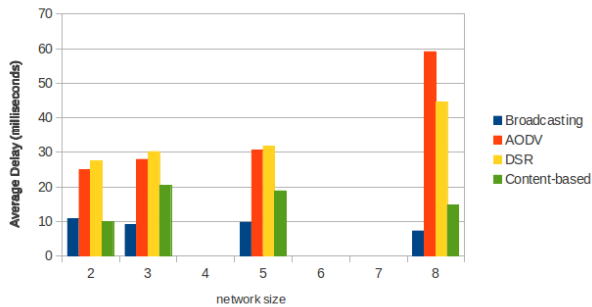

Figure 7. Average Delay vs. network size

5) Convergence time: Figure 8 shows that AODV and DSR convergence time increased as network size increased, which was caused by the route discovery process initiated by every node a packet is forwarded to discover the intended destination. The high convergence times indicate that AODV and DSR are more complicated than Broadcasting and Content-based Routing from setting up the network to making routing decisions. AODV and DSR incurred the highest delay and convergence times. AODV and DSR delay was influenced by the routing decisions that were made at the nodes. Convergence time for AODV and DSR is high because the route discovery process which is

initiated first takes longer to discover new routes and update routing tables. Broadcasting and Content-based Routing perform roughly the same on consideration of delay and convergence time. Delay is less than AODV and DSR because nodes do not deliberate about where to send a message or consult routing tables. Broadcasting and Content-based Routing had the lowest convergence times, meaning these protocols establish a network topology fairly quickly. And these protocols do not initiate route discovery like AODV and DSR. AODV and DSR have high convergence times, taking longer to form a network.
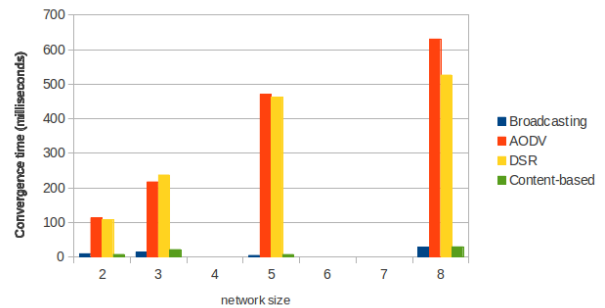

Figure 8. Convergence time vs. network size

6) Positive Response: Figure 9 shows that Broadcasting and Content-based Routing had the best positive response as the network size increased. As the network size increases, Broadcasting and Content-based routing have more paths to transmit data requests along. AODV and DSR, on the other hand, decide along which paths to send data requests. Depending on the information in their routing tables, not all available paths are used to transmit data requests. The reduced paths along which data requests are sent results in a lower positive response.
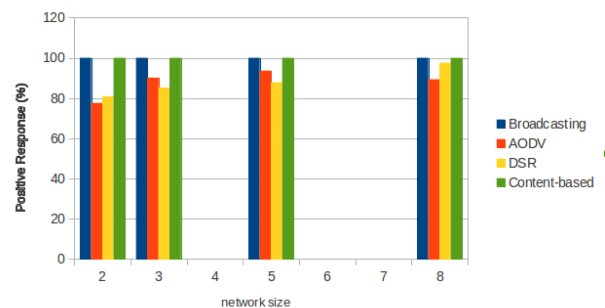

Figure 9. Positive Response vs. network size

VI. Conclusion

Two on-demand routing protocols, a broadcasting and content-based routing protocol were implemented in a mobile ad hoc network consisting of mobile phones. The results showed that simple, non-destination based algorithms such as broadcasting and content-based routing seem more suited for information dissemination in small mobile phone ad hoc networks in which mobile devices are always connected. A future challenge would therefore be to test the performance of these protocols in a real world setting.

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