# A Study of Different Routing Protocols for Mobile Phone Ad Hoc Networks Connected Via Bluetooth

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***Abstract*—The growth of mobile computing is changing the way people communicate. Mobile devices, especially mobile phones, have become cheaper and more powerful, and are able to run more applications and provide networking services. Mobile phones use fixed cellular infrastructure like base stations and transmission towers to enable users to share multimedia content and access the Internet anytime, anywhere. However, using telecommunications infrastructure introduces costs. Therefore, one of the solutions is to create impromptu ad hoc networks share information amongst users. Such networks are infrastructureless and organizing themselves, much like mobile ad hoc networks (MANETs).**

**This paper investigates how mobile phones with low power Bluetooth technology can be used to create ad hoc networks that allow them to share information. The mobile phones should be able to organize themselves at the application layer of the Bluetooth protocol stack for multi-hop communication. Routing becomes important in order to achieve efficiency in data communication. Several existing routing protocols were implemented and evaluated for this type of network to determine how efficiently they deliver data and deal with network disruptions like a device moving out of transmission range.**

***Keywords*-mobile ad hoc network; peer-to-peer; routing; performance; Bluetooth;**

## I. Introduction

Bluetooth devices are quite popular, with up to 906 million Bluetooth-enabled mobile phones shipped world wide in 2010 [1]. Many people in South Africa use their mobile phones for voice communication, text messaging and Internet access. While Bluetooth is still used for file sharing between devices in close proximity, data exchange using Bluetooth is not as prevalent as using cellular infrastructure to send text or instant messages however using these cellular services introduces extra cost. And WiFi connectivity may only be available on highend phones. This research considers the creation of a mobile ad hoc network, from henceforth referred to as a Bluetooth ad hoc network, consisting of mobile phones connected in a ubiquitous manner. While traditional cellular networks rely on fixed infrastructure, ad hoc networks are formed without central administration and fixed infrastructure. The devices rely on Bluetooth wireless channels to share information. Such a network allows the mobile devices to be self-organizing and self-configuring, connecting other devices out of transmission range. Devices should be able to look for and exchange information through the network without necessarily knowing which devices have the required information. Devices should be able to forward data in a multi-hop manner to devices out of transmission range by using intermediary devices. Each device is therefore responsible for maintaining routes to other devices and make routing decisions. Routing should efficiently use the limited resources of the mobile devices while at the same time adapting to the unpredictable topology changes caused by mobile devices moving out of transmission range or being switched off during transmission [2].

To form the Bluetooth ad hoc network, also referred to as a scatternet, Bluetooth-enabled devices form simple one-hop networks called piconets. Interconnected piconets form scatternets. To form a piconet, Bluetooth imposes a master/slave restriction between communicating devices: one device acts as the master of communication connected to a maximum of seven slave devices one-hop away. A slave device act as a master device in another piconet, creating a bridge between the piconets to form the multi-hop scatternet.

The need arises for mobile devices to be responsible for routing decisions in the Bluetooth ad hoc network. The Bluetooth ad hoc network will allow mobile phones to share information in a peer-to-peer(P2P) manner and allow intermediary mobile phones to act as routers between source and destination phones. Because the network uses concepts from the P2P and MANET paradigm, this paper considers how existing P2P and MANET routing techniques can be used in the Bluetooth ad hoc network. Therefore, a system design is presented that uses existing routing protocols and performance of these routing protocols is evaluated to determine which routing technique is suitable for data dissemination in the multi-hop ad hoc network under the restrictions imposed by the Bluetooth protocol.

The rest of this paper is organized as follows: Section II presents related work of routing techniques in Bluetooth ad hoc networks. In Section III, the design of the Bluetooth ad hoc network and the prototype application are presented. Section V presents the experiment setup and evaluation of the routing protocols used in the Bluetooth ad hoc network. Finally, the paper concludes in Section VI with a summary and suggestions about which routing protocol is suitable for routing Bluetooth ad hoc network envisioned.

## II. Related Work

Routing in mobile ad hoc networks (MANETs) is well researched in mobile ad hoc networks. Efficient routing is challenging because of device mobility and dynamicity - links become disconnected, causing network partitions and data loss. MANETs routing protocols are therefore designed to incur little overhead during communication between devices without causing too much data loss, and efficiently use the limited resources such as battery power and storage. Advanced On-demand Distance Vector Routing (AODV) and Dynamic Source Routing (DSR) are two such routing protocols that only initiate route decision making when they need to send a data packet [3], [4]. Therefore, the route discovery phases of these protocols need to be adapted for the Bluetooth protocol restriction.

Some previous research adapts MANET routing for routing in Bluetooth ad hoc networks using cross-layer optimizations which align the Bluetooth data link layer and network layer, thereby incurring little control overhead. Because Bluetooth requires that links be created only when devices really need to communicate, combining Bluetooth scatternet formation with routing to minimize control overhead [5]. Jarrah & Megdadi modified AODV to form scatternets. Their modified AODV consumes less energy in terms of battery by eliminating periodic HELLO messages and reducing the amount of route request messages generated during route discovery [6]. Huang et. al [7] also optimized AODV for Bluetooth again using a cross-layer optimization which assigns a load metric to the link between connected Bluetooth devices. Unlike Jarrah & Megdadi, Huang et. al's modified AODV sends out periodic HELLO packets to exchange link status information between the data link and network layers. Because of these differing approaches, this paper considers performance of these routing protocols such as broadcasting and content-based routing.

Other solutions use tree structures for scatternet formation. Tan et. al [8] create a scatternet in a tree-like structure between master/slave devices. Their tree-structure formation algorithm reduces scatternet formation latency.

## III. System Design

Design of the Bluetooth ad hoc network topology and prototype mobile application are presented in this section. The section also presents the design of the routing protocols to be tested in topology.

Figure 1 shows the network topology with mobile phones communicating in a P2P by forming a multi-hop ad hoc network using Bluetooth as a wireless channel. Each mobile phone is always aware of its one-hop neighbour. Phones out of transmission range are connected via intermediary phones creating multi-hop routes. This is however not done in a standard Bluetooth stack.

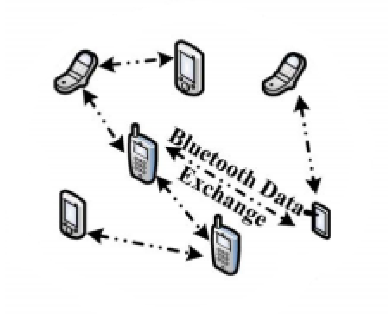


Figure 1. Network Topology [9]

Design of the prototype application, shown in Figure 2, implements a three-layered stack system. At the application layer, the user interface and data searching functionality are implemented; at the routing layer, routing and forwarding functionality are implemented; at the Bluetooth layer, communication between the mobile phones is implemented. The system developed is distributed between the mobile phones. At the start of communication, a mobile phone which initiates communication starts as a slave device and connects to a master device as per Bluetooth restrictions. However, the slave and master devices share the same functionality. When a request is generated or received at the application layer, the application layer searches local memory for the requested data. If the requested data is not in local memory, it is forwarded to the routing layer. At this layer, a routing protocol makes a decision about where to send the request. The Bluetooth communication layer, which creates the physical link between devices, exchanges information between the devices. Figure 2 illustrates this process.

### A. Routing

Four representative routing protocols were chosen for implementation. A brief discussion of their design is given in this section.

*1) Broadcasting:* Broadcasting propagates a new message through the network if it has not seen the message before or if the indicated time-to-live on the message has not expired. Otherwise the message is discarded [10], [11].

*2) Advanced On-demand Distance Vector Routing (AODV):* AODV and DSR are implemented based on the draft specifications by the The Internet Engineering Task Force (IETF) [12]. AODV maintains routing tables with route information indexed by unique sequence numbers to

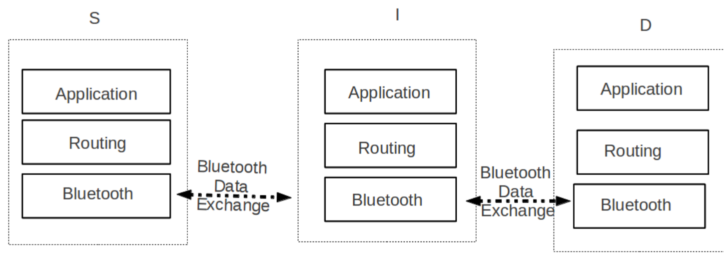


Figure 2. System Design. S is the source node, I, the intermediary node, and D, the destination node

distinguish routes. AODV periodically updates these routes using the route maintenance function.

*3) Dynamic Source Routing (DSR):* DSR only initiates route discovery when a node wants to forward data in the network [13]. Unlike AODV, DSR does not do route maintenance, but maintains routing tables with all discovered routes [14], [3], [15].

*4) Content-based Routing:* Devices in the network publish and subscribe to content. Devices that have content to share publish it throughout the network. Those interested in certain content send out a subscribe request [16], [17], [18], [19], [20], [21].

## IV. System Implementation

The prototype mobile application was developed on the *Java Platform Micro Edition* (J2ME) platform using the Mobile Information Device Profile (MIDP) 2.1 and the Connected Limited Device Configuration (CLDC) 1.1.

## V. Evaluation

### A. Experiment Setup

Experimentation was carried out using emulation in a controlled environment instead of simulation. The controlled environment provided comparable results unlike real world testing which raised challenges related to human interaction with the network when choosing master/slave devices. Additionally, simulation requires that the real world be modelled instead of observing behaviour of the mobile application developed. Figure 3 shows the physical topologies used during emulation.

### B. Performance metrics

This section defines the routing performance metrics chosen to evaluate routing performance.

*1) Total traffic:* Total traffic, $T_T$, refers to 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 total power will be used in the network by the mobile phones. Total traffic is calculated as follows:

$$T_T = \Sigma(msg * packet\_size) \tag{1}$$

The aim of this metric is to reflect how the routing protocol affect mobile phones in total when the network size and number of messages in the network increases. This is an important metric, e.g., did it influence the duration or battery lifetime of the mobile phones (perhaps as well as implicitly indicate willingness of mobile users to use the application).

*2) Data Traffic:* Data traffic, $T_D$, refers to successfully received data messages, $msg$ measured in bytes, received at each node. It excludes control messages. Data traffic is represented as follows:

$$T_D = \Sigma(msg * packet\_size) \tag{2}$$

The aim of data traffic is to show the effectiveness of the routing protocols in delivering only data packets.

*3) Control Traffic:* Control traffic refers to the difference between the total traffic, that is $T_T$, and data traffic, $T_D$, in the entire network. Control traffic includes all route discovery and route maintenance messages.

$$T_C = T_T - T_D \tag{3}$$

The aim of this metric is to determine how much total traffic is due to control traffic, and which routing protocols transmit to as many nodes as possible with little control traffic.

*4) Average Delay:* Average delay, $D_T$, is the average amount of time between when a message is sent from a source node and received at a destination node. It consists of processing delay at each node and transmission delay. The aim this metric is to determine which routing protocol is faster at transmitting messages through the network.

*5) Convergence Time:* In the Bluetooth ad hoc network, convergence time refers to the time taken to establish a stable network topology. Convergence time is determined by measuring the time difference to send the first route request

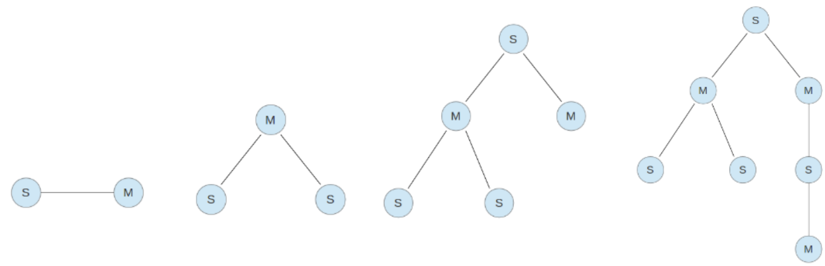


Figure 3. Tested topologies

from a source device and the last route reply to a source device.

$$C = t_{recv} - t_{sent} \tag{4}$$

The aim of this metric is to determine how quickly a network adapts to changes.

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

$$PR = \frac{rmsg_{recv}}{dmsg_{sent}} * 100 \tag{5}$$

The aim was to determine how well routing protocols responds to data requests.

### C. Message generation

During route discovery, a route request message is transmitted by the node that initiates a connection with its neighbours. Upon receiving a route request message, it initiates a route reply message. During data request transmission, a node sends out a data request of the form $\{$*type, value*$\}$. The node that initiates communication is usually the one that sends the first data request. 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.

### D. Results

This section compares the routing protocols according to the performance metrics that were defined. In this section, comparisons are made with reference to the bar graphs for each routing metric comparing the different routing protocols.

*1) Total traffic:* As seen in Figure 4, Broadcasting significant increase in total traffic as network size increased. Content based routing total traffic increased gradually as the network size increased. Master devices were responsible for responding to data requests and not forwarding requests unless they didn't have the data requested. AODV and DSR had slightly more total traffic than Content-based routing

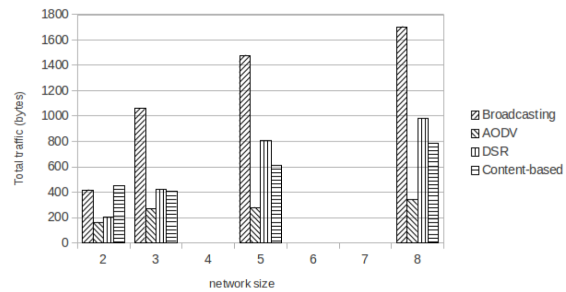


Figure 4. Total traffic vs network size

because it forwarded a request to all connected neighbours instead of choosing which node to forward the request or packet to.

*2) Data traffic:* Figure 5 shows that as the network size increased AODV, DSR and Broadcasting data traffic increased significantly. Content-based routing only transmitted data to the closest one-hop neighbour and did not propagate a packet like Broadcasting throughout the network, or like AODV and DSR that forward a packet until its time-to-live had expired or it reached its intended destination.

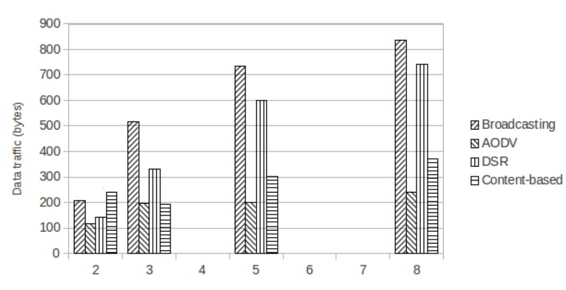


Figure 5. Data traffic vs. number of nodes

Broadcasting and Content-based routing generate more data traffic because these protocols do not make complicated routing decisions. If a data request was never seen or its time-to-live hasn't expired, it is simply sent to all connected neighbouring devices. Where as, AODV and DSR decide where to send the requested data.

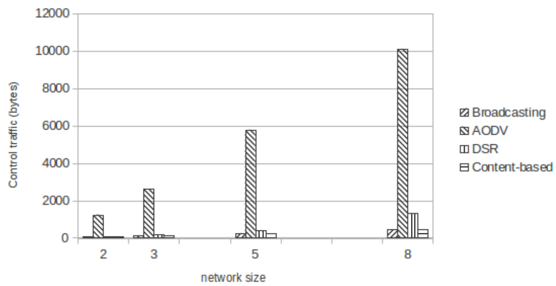


Figure 6. Control traffic vs. number of nodes

*3) Control traffic:* The control traffic incurred by AODV increases significantly as the network size increases as shown in Figure 6. AODV has more control traffic because of the route discovery and route maintenance processes initiated periodically. However, DSR control traffic remains significantly less than AODV because control packets were not generated periodically. Control traffic for Broadcasting and Content-based Routing was significant less than AODV and DSR because these protocols only initiated route discovery at the very beginning at network setup. No route maintenance was initiated either.
In summary, AODV and DSR have a significant amount of control traffic. This control traffic is due to the control packets used during route discovery and route maintenance.

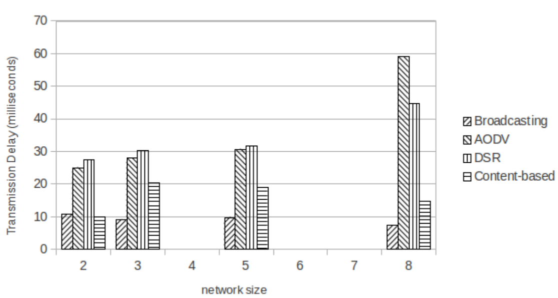


Figure 7. Delay vs. number of nodes

*4) Delay:* Figure 7 shows AODV and DSR increased as network size increased. Broadcasting and Content-based Routing show a decrease in delay as network size increases. Shorter delays occur with Broadcasting and Content-based routing because every connected neighbour is simply forwarded a message which makes available more devices to reply to messages quickly.

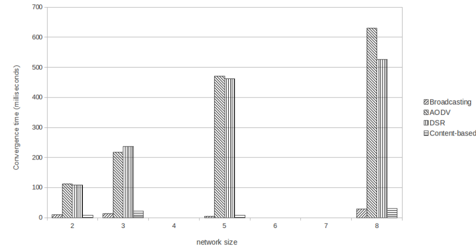


Figure 8. Convergence time vs. number of nodes

*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 account 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 connect nodes in the network.

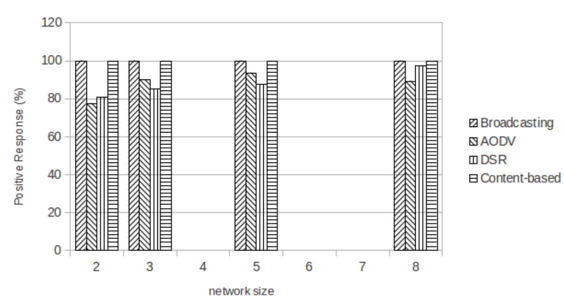


Figure 9. Positive Response vs. number of nodes

*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.

## VI. Conclusion

Different routing protocols were compared by implementing the routing protocols in a prototype mobile application which allowed mobile devices to form a multi-hop ad hoc networking connected via Bluetooth. The prototype was tested in a controlled environment via emulation to obtain steady data. Emulation results show that Broadcasting and Content-based Routing outperform AODV and DSR in average delay and convergence times. AODV and DSR had the highest control traffic caused by route discovery and route maintenance processes. Broadcasting and Content-based Routing had the best positive response because these protocols do not reduce the paths along which to send data by consulting a routing table. These observations suggest that Broadcasting and Content-based Routing are more suited for data dissemination in small, sparse, stable mobile phone Bluetooth ad hoc networks.

## VII. Future Word

A future real world study in settings such as conference and class rooms will need to be conducted to determine which routing protocol is better suited for the Bluetooth ad hoc network.

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