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Abstract

Ad-hoc networks consisting entirely of simple mobile phones can be used to deploy village level telephony. We investigate a novel application for such networks – a peer-to peer community radio service. We envision a system, where any user in the network is equally empowered to generate and distribute audio content to the entire network, using his or her mobile phone. This study concentrates on a critical aspect of this service – the choice of the network-wide broadcast protocol. Using extensive simulations, we evaluate the suitability of various broadcast techniques for a rural peer-to-peer mobile adhoc network. Our simulations identify the best choice of protocols under various village network conditions while simultaneously identifying limitations of the current protocols.

Keywords - mobile adhoc network, community radio, broadcast protocols, simulations

I. INTRODUCTION

Mobile ad hoc networks (MANETs) are networks that spontaneously spring up when mobile devices equipped with short-range communication capabilities are brought together. Nodes in a MANET are not only capable of directly communicating with one another, but can also act as intermediaries for nodes which are mutually out of range from each other. A message from the source might go through multiple intermediary nodes before reaching the intended recipient. Such networks have typically been used in scenarios like disaster recovery and military operations in hostile regions, where traditional centralized network infrastructure is unavailable.

More recently, mobile ad-hoc networks consisting entirely of simple mobile phones have been proposed as a means to provide village level telephony [1–3]. Ultra-rural regions of many developing countries do not have access to any kind of digital communication infrastructure -- overwhelmingly due to economic reasons. MANETS by their very definition of not requiring centralized infrastructure; and comprising only of relatively in-expensive mobile devices are a promising communication alternative for such communities.

This paper considers a new application for a village level mobile ad-hoc network – a community radio service (first proposed by us in an earlier paper [4]. Community radio has been seen a powerful medium not only for broadcasting information but also for empowerment via the creation and dissemination of local content [5]. Though traditionally community radio has followed a centralized model in terms of content generation and filtering, we envision a true peer-to-peer service where any participant can be the source of audio-content. This entails that every phone in the ad-hoc network be able to reliably and efficiently broadcast audio content to every other phone in the network (via intermediary hops when required).

While there is considerable past literature on broadcast techniques for mobile ad-hoc networks, earlier studies have chiefly used broadcast packets for topology discovery as a part of the routing protocol. Hence the metrics for evaluating broadcasting techniques have largely concentrated on a very different application than the one this study focuses on. We examine the suitability of various broadcast protocols for a novel MANET application – a rural community radio service.

The following are the main contributions of this work:

(i) The paper identifies unique characteristics of a rural peer-to-peer (p2p) mobile ad-hoc network and the features required for a robust media broadcast technique for this environment.

(ii) A village-level adhoc p2p phone network was modeled and extensive simulations were conducted to evaluate the suitability of different classes of broadcast techniques for a community radio service on this platform.

(iii) relative advantages and disadvantages of each protocol were identified – allowing the identification of the best choice of protocol for different network scenarios.

The paper finds that among the four protocols that were evaluated, neighborhood-knowledge broadcasting schemes work best. ASBA (the Adaptive Scalable Broadcast Algorithm), which uses 2-hop neighbor knowledge for broadcasting decisions, seems the best choice for the application in question. While another neighborhood-knowledge technique – AHBP (Ad-hoc Broadcast Protocol) is more efficient than ASBA in terms of reducing redundant messages, it fails to perform well under rapidly changing network topologies.

The rest of the paper is organized as follows: The next section discusses related work on broadcasting in MANETS. Section 3 details the desired characteristics of the broadcasting technique for our application, and a description of the protocols chosen for further evaluation. In Section 4, we describe the simulation set-up, experiments conducted and metrics for evaluation. Section 5 contains the results of the experiments. We conclude in Section 6 with a discussion and directions for future work.

II. RELATED WORK

Existing MANET broadcast protocols that are distributed in nature can be classified into four broad categories, as proposed by William and Camp [[6]: (i) Simple Flooding (ii) Probabilistic Schemes (iii) Position Based Methods and (iv) Neighbor Knowledge Schemes. Though there is substantial work that examines hierarchical broadcasting and overlay based (also known as cluster-based in the literature) broadcasting protocols, we do not consider those in this study.

Our application hinges on a pure, distributed network and hence only protocols that are truly distributed in nature are considered.

(i) Simple Flooding: The most straightforward of all broadcasting schemes is simple flooding [7], [8] . Each node re-broadcasts every unique message it receives, but only once. Given its ease of implementation, flooding is the broadcasting algorithm of choice in most MANET routing protocols. However, while flooding is reliable and reasonably efficient in sparse networks, the indiscriminate re-broadcasting makes it highly inefficient in denser networks, creating what is called the *broadcast storm problem* [9].

The underlying aim of more sophisticated broadcast protocols is to ensure that a message reaches all the nodes in the network while simultaneously reducing the number of rebroadcasts. In short, an efficient broadcast protocol should be able to alleviate the broadcast storm problem without compromising on the reach of the message.

(ii) Probabilistic Schemes**:** In probabilistic schemes, each node forwards only a certain percentage of messages it receives, in a bid to alleviate the broadcast storm. We further classify probabilistic schemes under two sub-categories Simple Probability and Duplicate Counting schemes. In the Simple Probability scheme [9], [10], the probability (*p*) with which a message is forwarded is predetermined and the same at every node in the network; when the value of *p* equals 1, the scheme reverts to simple flooding. Hass et. al.[10] report that a probability between 0.6 and 0.8 ensures that most nodes in the network receive the broadcast message. The optimal value of *p* however differs for different node densities (measured by the number of neighbors of a node). Since a network may not have uniform density throughout, the probability scheme can be further improved if p is allowed to vary along with the local node density.

Duplicate counting schemes [9], [11–13], also known in the literature as *counter-based* schemes, estimate the local density of the network (the number of neighbors) by keeping track of the number of duplicate messages they receive. A large number of duplicate messages denote a dense neighborhood and vice-versa. These schemes aim to facilitate a high number of re-broadcasts in low density areas and fewer re-broadcasts in denser areas of the network. Variations in this category include (1) using a random delay before re-broadcasting a message during which the number of duplicates are counted. If the number of duplicates are above a threshold the message is dropped [9] (2) using the number of duplicates to adjust the value of *p* at each node [11], [12] and (3) using the number of duplicates and the maximum signal strength to dynamically adjust the value of *p* [14]. Duplicate counting schemes are considered lightweight since unlike neighborhood knowledge schemes, they do not need extra messages to map the network topology.

(iii) Position Based Methods try to estimate how much additional area will be covered by a re-broadcast. Intuitively, two nodes which are close together will roughly have the same coverage. These schemes can further be classified into two categories (1) distance-based schemes and (2) location-based schemes.

Distance-based schemes [9], [15], [16] estimate the distance between the receiver of redundant messages and the sources of those messages. Ni et.al [17] propose using the signal strength at the receiver as one possible way to calculate the distance of the source node. If any of the sources are considered close enough to the receiver (according to a pre-determined threshold value), the message is not re-broadcast. Liarokapis et.al [15] propose a variation of the distance-based scheme called DibA, which dynamically adjusts the distance threshold value depending on the number of duplicate messages received. Pampa (Power-Aware message propagation Algorithm) [16] is a fully distributed algorithm which uses the signal strength of a message to estimate the distance between two nodes. Like in the counter-based schemes, each node using Pampa waits for a certain *delay* and rebroadcasts only if the number of redundant messages are below a threshold. However, the *delay* at each node is different and depends on the distance of that node and the source. Hence nodes further away from the source are encouraged to re-broadcast first.

Location-based schemes [18], [19] entail that each node knows its exact 2-coordinate location, using GPS or similar technology. The coordinates of the source node are sent as part of the broadcast message. Each node can then calculate the exact additional coverage achieved by a re-broadcast. The six-shot broadcast [18] uses location to fine-tune the re-broadcast *delay* at a node, to ensure that nodes near six strategic positions are the forwarders.

(iv) Neighbor Knowledge Schemes use one-hop or two-hop neighbor topology to decide whether to re-broadcast a message. There are two variations in this category depending on whether the sender or receiver makes the decision to rebroadcast a message. In receiver based methods each node decides for itself, whether it will re-broadcast a particular message. In sender based methods, upstream nodes decide which downstream nodes will act as relays.

In receiver based methods [6], [20–23] the node receiving a messages determines if a re-broadcast will reach additional nodes. The Scalable Broadcast Protocol (SBA) [20], uses 2-hop neighborhood knowledge to make this decision. More recently, variants of SBA have been proposed where the delay before re-broadcasting is fine-tuned according to the congestion in the network [6], [21] or the number of neighbors of a node [23].

In sender-based methods [22], [24–26] each sender designates a sub-set of its neighbors as forwarders for a message. The Ad-Hoc broadcast protocol (AHBP) [26] uses two-hop neighborhood knowledge to decide the most efficient sub-set of downstream nodes that should rebroadcast, so that all nodes in its two-hop neighborhood are covered. More recently Liu et.al [27] proposed a scheme that requires only one-hop neighbor knowledge while K & Bhargav [22] proposed an improvement to Liu et.al.'s algorithm in terms of time complexity.

Our study uses detailed simulations, to evaluate representative protocols from each of these categories, along the various dimensions identified for a rural media broadcast service. In earlier work [4], we had first proposed using mobile ad-hoc networks for a rural community radio service. This paper goes a step further with a detailed quantitative evaluation of broadcast protocols for the same. To our knowledge, ours is the first study to model a village-level ad-hoc network and evaluate broadcast techniques for a community-radio service. In Section IV, where we describe our simulations, we also discuss how our simulation model set-up differs from past attempts at modeling a mobile ad-hoc network.

III. BROADCASTING DETAILS

By definition, a broadcast message should reach every node (or at-least a large percentage of nodes) in the network. Broadcasting protocols used in mobile adhoc networks are usually measured on two dimensions – their reachability (or delivery ratio) and efficiency. The delivery ratio measures how many nodes actually received the message (assuming there are no partitions in the network). The efficiency of a protocol measures how many re-broadcasts were needed for network-wide delivery. The efficiency of a protocol is especially important in our context, as the devices in question are basic mobile phones with very limited battery life. Moreover, often in rural scenarios, users have to travel a kilometer or more to charge their phones. Hence, it is important to conserve the power of these devices, and fewer devices needed to broadcast a message means more battery power conserved over the collective network.

Apart from efficiency and delivery ratio, we identify four more desired characteristics of the broadcast protocol for our particular application – a rural community radio service.

A. *Desired Protocol Characteristics*

Minimized Latency: A radio service deals with streaming audio content. Each audio packet may go through multiple hops before reaching a particular node. To ensure adequate voice quality, it is paramount that data-packets are transmitted without additional delays at each hop. Hence the broadcast protocol should attempt to minimize latency.

Adaptability to Mobility and Network Topology: Our application is targeted towards rural communities where users will potentially be mobile throughout the day. In a typical Indian village for example, people live in dense clusters of dwellings. They would typically leave for work to the nearby fields or marketplace early in the morning, and return home at dusk. Hence the adhoc network formed via their mobile phones can be expected to be sparse in some regions (like the fields) and dense in others (like the marketplace). Similarly, in the evenings, with everyone returning home, the network would consist of dense clusters. The broadcast protocol should hence be able to adapt to a high degree of mobility and varying local network densities.

Robustness to Heavy Traffic: We can expect the audio-streaming application to consist of a large amount of data-packets. Hence it is desired that the protocol function well in spite of moderate congestion in the network.

Simplicity: Devices which can be afforded by the target population of our application tend to be basic mobile phones. These devices have resource constraints in terms of CPU power, battery life and memory. Moreover, special features like Global Positioning Systems (GPS), may not be available on these devices. The broadcast protocol should be able to operate within the limited feature set that is available on these devices.

B. *Broadcast Techniques Chosen for Our Study*

While we have discussed numerous protocols in our related works section, an experimental evaluation of all of these would have been infeasible. We instead chose one well-known protocol to represent each of the categories we had described earlier. We chose Simple Flooding as the base case and Counter-Based protocol [9] from Probability Schemes. We chose the counter-based scheme as it perfectly captures the *wait and count* model of duplicate-counting schemes. From Neighbor Knowledge schemes, we selected one each from the two types – receiver based and sender based. We picked Adaptive-SBA (ASBA) [6] to represent receiver-based rebroadcasting since it has been shown to adapt better to network congestion than regular SBA. For a sender based scheme, the Ad Hoc Broadcast Protocol (AHBP) [26] was chosen, as its core algorithm is similar to many of the other sender-based schemes like Multi-Point Relaying and Dominant Pruning [25] , yet it has been shown to perform better than most others in its category.

Position based schemes require extra hardware support in terms of either GPS or accurate measurement of signal strength. Since we cannot assume that all the mobile devices in our network will contain these features, we do not consider position-based schemes for our simulations.

We now describe the chosen protocols in detail:

Simple Flooding: Each node in the network rebroadcasts a message, but only the first time it receives it. With no partitions in the network, both the delivery ratio and reachability for Simple Flooding is 100 percent. Simple Flooding is considered as the base case for comparison with other more sophisticated protocols.

Counter-Based Scheme: This scheme proposed by Tseng et; al. [9] is based on the intuition that there is an inverse correlation between the number of duplicate packets a node receives and the chances of reaching new nodes with a re-broadcast. When a node receives a new message, it waits for a certain amount of time (called the Random Access Delay or RAD) before deciding whether to rebroadcast the message. if the number of duplicate messages received during the RAD exceed a threshold , the message is not rebroadcast. The exact functioning of the algorithm follows:

Upon receiving message m

If m has not been received earlier

Initialize counter of m to 1

Wait for a Random Delay

If counter of m < Threshold

Re-broadcast message

Else

Increase counter of m by 1

The counter-based scheme ensures lesser rebroadcasts in dense regions of the network and more rebroadcasts in sparser regions. However the performance of the counter-based schemes is highly dependant on the values chosen for the threshold. Tseng et.al.[17] show that a threshold value of 3 or 4 is effective in dramatically reducing the number of re-broadcasts. However, they find that a threshold value greater than 6 is not effective in saving re-broadcasts, especially in sparse networks. Hence, for our experiments, we use a threshold value of 3. Note that the RAD time used to delay the transmission of a rebroadcast is randomly chosen between 0 and Tmax seconds. In our simulations, we use a value of 0.01 seconds for Tmax.

Adaptive Scalable Broadcast Protocol (ASBA): We first describe the basic SBA protocol as proposed by Peng et al.[20] and then discuss the adaptive variation proposed by William et.al. [6]. SBA requires a node to know all its two-hop neighborhood nodes. To facilitate this knowledge, each node sends periodic "hello" messages to all its neighbors. The hello message contains the nodes identity as well as a list of all its known neighbors. Thus every node builds a partial network map of all nodes within a two-hop radius of itself.

The SBA protocol works as follows: Suppose a node (say R) receives a broadcast message *m* from node S. R can find out all common neighbors between itself and S which would have already received *m* from S. If there are additional neighbors of R which were not covered by S, then *m* would be scheduled for a re-broadcast, after a random delay (RAD). During the RAD, if a duplicate *m* is received from some other node, R would again determine if any new nodes can be reached by a re-broadcast. At the end of the RAD, if some neighbors of R have not yet received *m*, then the message is rebroadcast.

The RAD time used to delay the transmission of a rebroadcast is randomly chosen between 0 and Tmax seconds. However, Williams and Camp [6] show that in congested networks, a higher value of RAD is effective in increasing the delivery ratio. Hence it is desirable to adjust the RAD Tmax value to the local congestion in the network and Adaptive-ASBA attempts to do exactly that. ASBA estimates the congestion around a node by keeping track of the number of packets received per second at that node. If the packet arrival rate is greater than a threshold then the Tmax value is set to a higher value. ASBA estimates this threshold as 260 packets per sec which roughly translates to a broadcast origination rate of 50 packets/second in our simulations. If the arrival rate of packets is greater than 260/second on average, then the RAD Tmax is set to 0.05 seconds, else it is set to 0.01 seconds .

Ad Hoc Broadcast Protocol (AHBP): Like the Scalable Broadcast Protocol, the Ad Hoc Broadcast Protocol [26] requires that each node maintain its two-hop neighborhood knowledge via periodic 'hello' messages. However, unlike SBA, AHBP is "sender-based" implying that upstream nodes decide which downstream nodes will rebroadcast a message. Nodes that are designated as Broadcast Relay Gateways (BRGs) are the only ones allowed to re-broadcast a packet. When a message is received at a node, the list of BRGs is also included in the header of the message. If a node finds itself in the BRG list, it re-broadcasts the message or else the message is dropped. The message header also includes the path of nodes that the message has taken to reach the current node. Each BRG uses two pieces of information for calculating which of its neighbors should be designated as BRGs -- the path of the message and its own 2-hop neighborhood topology. Using this knowledge, AHBP tries to construct (dynamically and in a distributed fashion) a connected dominating set (CDS) for all the nodes in the network.

We now describe the operation of the AHBP protocol:

Suppose a new message *m* is received at node R from node S. Also suppose that P is the set of nodes in the path followed by *m* and N and M are the set of 1-hop and 2-hop neighborhood of R respectively. The following steps are followed at R to select a subset of N as BRGs:

1) From M and N, remove all nodes which are in P, or are neighbors of P to get reduced sets M_r and N_r respectively.

2) From M_r find all nodes that can only be reached by one node in N_r. Designate these nodes as BRGs.

3) Find the resultant set of nodes (C) covered by the newly designated BRGs. Update N_r and M_r to exclude C from them.

4) From N_r , find the node n that would cover the most number of nodes in M_r . Designate node n as a BRG.

5) Repeat steps 3 and 4 till all 2-hop neighbors of R are covered.

IV. Simulation SETUP

We evaluate the performance of the chosen protocols by simulating a village level ad-hoc mobile network. We use the discrete event network simulator NS-2 [28] and its extension for mobile wireless networks provided by the CMU Monarch project, to model a village network.

The link layer of NS-2 utilizes the complete IEEE 802.11 MAC implementation. Usually the RTS/CTS/ACK scheme (Request-to-send/Clear-to-send/Acknowledgement) is used to reserve the wireless channel and avoid collisions due to a hidden node. However, while this works well for unicast messages, the scheme is too cumbersome for broadcast messages. Thus generally, broadcast messages are sent when the node assesses a clear channel with no explicit coordination with other nodes. This however means that collisions from hidden nodes are possible. We make the same assumption in our simulations and do not use the RTS/CTS/ACK scheme for broadcasts.

Node movement is simulated using the random waypoint model [29]. Each node moves towards a randomly selected co-ordinate within the rectangular area selected for the network. In our experiments, the default speed of a node is 10 meters per second which is the typical speed of a bicycle. We also experiment with other speeds as detailed later. Once a node reaches the destination it randomly selects another co-ordinate to move to.

Villages vary greatly in their population and spread and there is no such thing as a typical village size. According to the Indian 2001 census for example, out of around 600,000 villages in India, more than 200,00 villages have a population under 500 persons, while around 4000 villages have a population greater than 10,000 persons. Our application is targeted towards the more rural and remote villages which do not have traditional communication infrastructure and these villages typically tend to be small. In our simulations, we modeled relatively small villages with an area of one square kilometer and up to a maximum of 100 mobile phones.

Each node is assumed to have a transmission range of 250 meters. Although the Serval project [1] was able to achieve a transmission range of up to 500m for their ad-hoc phone network, it was under specific conditions of a flat, unobstructed terrain. We assume a more conservative estimate of 250 meters.

Our simulations cover a range of network densities: from around 4 neighbors per node (could represent workers in the fields) to about 20 neighbors per node (could represent the marketplace or clustered dwellings). We also study scenarios of heterogeneous (non-uniform) network density. The data packet size is set to 512 bytes to simulate audio packets. Table 1 contains the simulation parameters used in our study.

One node is randomly chosen as the source for each broadcast message that is introduced in the network, and that packet is broadcast to all the nodes in the network, according to the protocol being evaluated. We experiment with a range of broadcast frequencies – from 1 message per second to 80 messages per second.

Although many other studies have looked at broadcasting techniques for a mobile ad-hoc network, the scenarios and applications considered in the past have been very different from our scenario of a village social network. In many studies the network area (typically 350 * 350 meters) is too small to be relevant for our scenario [6]. Furthermore, most studies [26], [11], [23] assume uniform network densities whereas our network can be expected to be composed of dense clusters along with sparser regions.

We designed different experiments to evaluate the broadcast protocols on the various dimensions described in Section 3. Each experimental scenario was simulated five times, with different initial topologies and packet origination patterns, for a total of 110 simulation runs for each of the four protocols. The results reported are the average for five runs and where standard deviations are large, they are also reported.

Table 1: Simulation Parameters used in experiments

Simulation Parameter	Value
Simulator	NS2 Version 2.29
Network Area	1000 m X 1000m
Transmission Range	250 m
Number of Nodes	20 – 100
Data Packet Size	512 bytes
Simulation Time	1100 seconds
Maximum IFW Length at Node	50
Node Speed	0 – 20 meters/second (default =10)
Broadcast packets per second (pps)	1-80 (default = 4)
'Hello' message Interval (used for ASBA and AHPB)	1/second

We now describe each experimental setup and the parameters measured in each scenario.

Experimental Setup 1: Adaptability to Network Topology

To observe how well each broadcast protocol adapts to different network topologies, two cases were studied – networks with uniform and non-uniform densities. In the first case of uniform networks, various network densities from sparse (4 neighbors per node on average) to very dense (around 20 neighbors) were used. Nodes were randomly placed in the network and remained static for the length of the simulation. The density of the network was changed across experiments, by increasing the number of nodes in the same area, from 20 to 100. We measured both the delivery ratio and the number of rebroadcasts for each protocol under these different network densities. While Simple Flooding is known to be highly inefficient in dense networks, this study seeks to see how the other protocols with more sophisticated algorithms behave.

The purpose of the second study was to evaluate the protocols when the network density was non-uniform, since a network which is denser is some parts and scarce in others, more closely resembles a village level mobile-phone network. To achieve this, we divided the rectangular area of the network into four equal quadrants and placed a certain percentage of the nodes only in the first quadrant. The rest of the nodes were randomly placed throughout the network. Depending on what ratio was used, this gave rise to various non-uniform network densities – typically a dense cluster in one region and a scattering of nodes in the rest or the area. We conducted experiments for 100 nodes, using ratios 50:50 and 80:20, where the first number denotes how many were placed in the smaller quadrant. Again, the nodes were held static for the length of the simulation.

Experimental Setup 2: Robustness to Mobility

This study evaluates each protocol's ability to react to node mobility. We use the random way-point model with zero pause time for node movement. The speed with which nodes move is varied from 1 meter per second (m/s) to 20 meters per second. 1 m/s can be considered typical walking speed and a bicycle might travel at 8 m/s. However the maximum speed of 20m/s would imply motorized vehicles constantly zipping by at top-speed and seems quite un-realistic. However, we use the last scenario to evaluate the protocols under extreme situations of mobility. The total number of nodes used for this experiment was 60, and the pps (packets per second) value was set to 4.

Experimental Setup 3: Latency

To measure the latency in broadcasting a message, we record the time when a broadcast message was first introduced in the network. We then record the time when the last node in the network received that message. The difference between these two time-stamps is considered the latency for that message. The average of this measure for all messages in a simulation run gives us the average latency introduced by a protocol. Other experiments on MANET based village-level telephony [1] have observed that voice-quality is acceptable up to six or seven intermediary hops. We measure the latency in message transmission for networks of varying sizes, so as to study the effect of increasing the number of hops in a route. In this experiment, nodes are kept static so that mobility patterns do not interfere with the latency measurements.

Experimental Setup 4: Robustness to Heavy Traffic

This experiment assesses the performance of the protocols under congested network conditions. The congestion in the network can be increased by either increasing the packet size or the number of packets (messages) sent out per second. We chose to keep the packet size constant and increase the pps (packets per second) value. Static networks with 100 nodes each, were studied, with the pps value ranging from 1 to 80 packets per second.

V. RESULTS AND DISCUSSION

1. Adaptability to Network Topology

Figure 1 plots the number of rebroadcasts each protocol generates, in networks of uniform density. The x-axis contains the number of nodes in the network and is thus proportional to the density of the network. Figure 2 contains the Delivery Ratio for the same set of protocols and networks. [1]

As seen from Figure 2, all four broadcast protocols were able to reach around the same number of nodes. For sparse networks (40 nodes) the delivery ratio for all of them was around 87% where as for denser networks the delivery ratio went up to 100% for all four protocols. (Note that the consistently lower reach for all protocols in the sparser networks can be attributed to network partitions).

However, the efficiency of each protocol varied drastically. As seen in Figure 1, flooding was consistently less efficient than all the other protocols. While the difference is less stark in sparse networks, flooding is highly inefficient in dense networks and expectedly so. The other three protocols reach the same number of nodes with significantly less number of re-broadcasts. AHBP is the most efficient, with only around 20% of the nodes rebroadcasting in the very dense setting of 100 nodes. Compare that to the counter-based scheme, where on average, more than 70% of the nodes rebroadcast a message. ASBA is consistently more efficient than both Flooding and Counter-Based, but has significant more re-broadcasts than AHBP when operating in very dense networks.

[1] We have not included data for 20 node networks as these networks turned out to be very sparse and hence highly partitioned.

The neighbor knowledge schemes (ASBA and AHPB) while being significantly more complicated than counter-based, in a sense justify their additional complexity by being far more efficient.

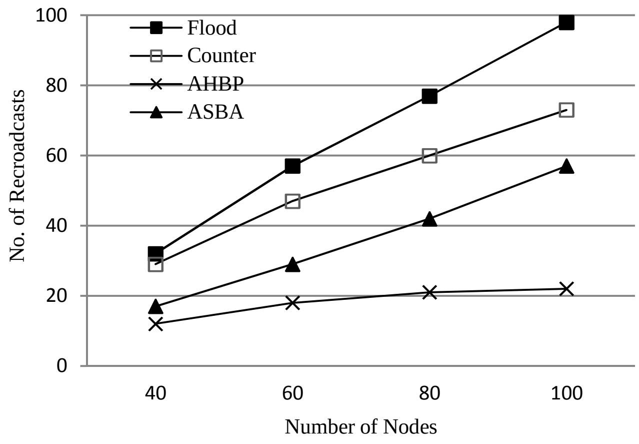

Figure 1: Number of nodes rebroadcasting a message versus number of nodes in the network

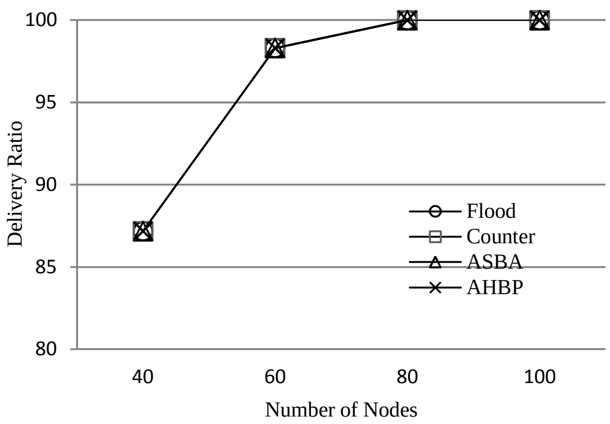

Figure 2: Delivery Ratio (percentage of nodes receiving a message) versus the number of nodes in the network

Figures 3 and 4 contain results for the non-uniform network density. Recall that we wanted to test the performance of the protocols when the network consisted of a dense cluster of nodes along with other sparse regions. We report results for three different network setups – Random (as a baseline), 50-50 and 80-20. In Random, the nodes were randomly placed in the whole region. In the other two configurations, the first number denotes how many were placed together in a dense cluster and the second number denotes how many were scattered randomly in the rest of the network.

As seen in Figure 3, ASBA seems to adapt better to changing network densities. Notice how the number of rebroadcasts drops sharply from the random scenario to the 50:50 scenario for ASBA. Our rational for this observation can be explained as follows: The 50:50 scenario consists of one dense cluster of nodes and hence should require less re-broadcasts within that region. If the protocol adapts well to the local density then the overall number of rebroadcasts should lessen significantly from the random case. While all three protocols show a drop in the number of rebroadcasts, ASBA has the sharpest drop and hence seems to have adapted the best. Similarly, in the 80:20 scenario, the dense cluster has now grown bigger than in the 50:50 case, and fewer nodes are scattered but are further away. As can be seen from Figure 4, the delivery ratio drops for all four protocols, leading us to infer that many nodes (in the scattered set) cannot be reached. In an effort to reach these scattered nodes, the broadcast protocol needs to rebroadcast more aggressively in the sparser regions. Again, all three protocols (except for flooding), have increased the number of broadcasts, but ASBA's increase is the sharpest. This leads us to infer that ASBA adapts best to the local network density.

The reason for ASBA's adaptability lies in how the protocol works -- it dynamically adjusts its RAD time to the local density around itself – something that counter-based and AHBP are unable to do.

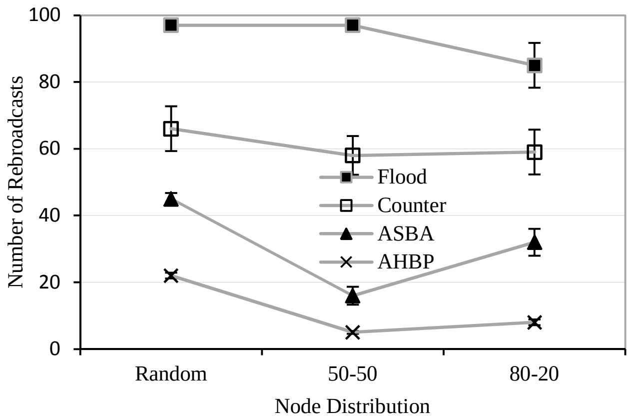

Figure 3: Number of Rebroadcasts in networks with non-uniform node distribution

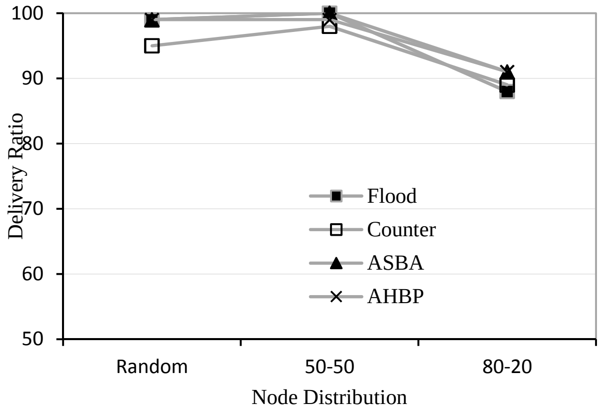

Figure 4: Delivery Ratio in networks with non-uniform node distribution

2. Robustness to Mobility

Figure 5 and 6 plot the performance of the different protocols as the speed with which nodes move is increased. As can be seen from Figure 5, Flooding and Counter-based have a constant number of rebroadcasts, even as the speed of the nodes increase. Both also maintain high delivery ratios (Figure 6) as the speed increases. However, Counter-based is far more inefficient than ASBA and AHBP (45 re-broadcasts as compared to around 30 and 12 respectively). Although AHBP is the most efficient, its delivery ratio suffers when the nodes are highly mobile. As seen in Figure 6, AHBP's delivery ratio steadily declines as the mobility in the network increases. When nodes travel at 20 meters /second AHBP's delivery ratio drops to 90%. ASBA however does not suffer in its reach, and maintains a high delivery ratio for all degrees of node mobility.

AHBP's poor performance under a changing network topology can be explained as follows: recall that in AHBP, upstream nodes decide which downstream nodes will act as relays. If a node (say B) selected by an upstream node (say A) to act as a relay, moves to another location then the nodes that B would have covered are now not reached. ASBA (the other broadcast protocol that depends on neighbor knowledge) however does not suffer as drastically from a changing topology. Recall that in ASBA, each node decides for itself, whether it will re-broadcast a message or not. Hence, if a node moves to a new location and has new neighbors, it automatically decides to re-broadcast. Thus, ASBA adapts to increased mobility by increasing the number of nodes that rebroadcast (as seen in Figure 5), whereas the number of nodes re-broadcasting actually decrease for AHBP.

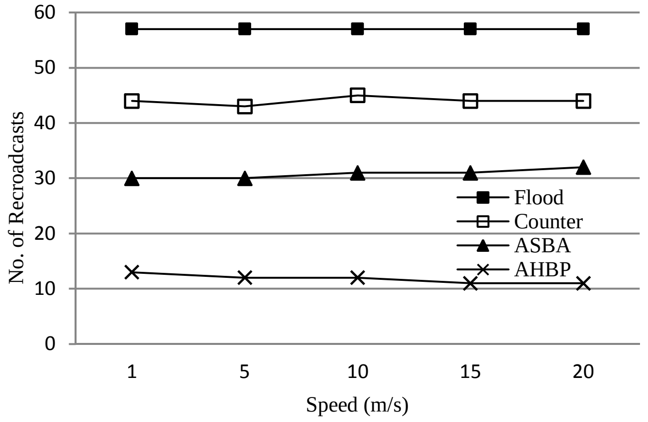

Figure 5: Number of re-broadcasts versus node speed

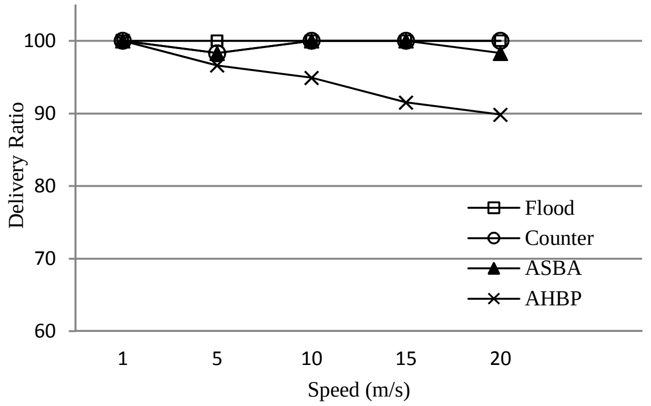

Figure 6: Delivery Ratio versus node speed

3. Latency

Figure 7 shows the latency incurred by each protocol, as the number of nodes in the network is increased. Note that, as the number of nodes increase, the average number of hops between a source and destination also increases. As expected, as the number of hops increases, the end-to-end latency increases for all the protocols.

Flooding consistently has the lowest latency – this is expected, as it is the simplest protocol with the least computational overhead. AHBP has lower latency than Counter-based and ASBA. Recall that both Counter-Based and ASBA use a RAD interval as part of the protocol. That is, both protocols wait for a certain interval before a message is forwarded. This leads to higher latencies for Counter-Based and ASBA than the others. AHBP does-not use a RAD time, and thus saves a few milliseconds in its execution time, leading to lower latency for messages.

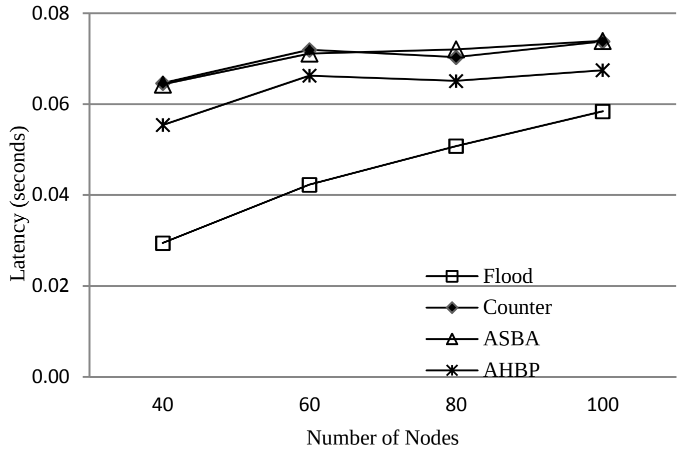

Figure 7: Latency incurred by each protocol as size of the network increases.

4. Robustness to Heavy Traffic

Figures 8 and 9 show the performance of Counter, ASBA and AHBP protocols as the traffic in the network increases (Flooding showed very erratic behavior under heavy congestion, and the standard deviation for the measurements was too high to justify plotting its statistics). As can be seen from Figure 9, all three protocols break down under very heavy traffic (when 40 packets per second or more are injected into the network). None of the broadcast protocols are able to operate under this heavy congestion. Notice that, till a value of 10 pps, all three protocols have high delivery ratios (Figure 9), with Counter being the least efficient and AHBP being the most efficient (Figure 8).

However, the robustness of each protocol under heavy traffic can be gleaned from their behavior when the pps value is 20. As shown in Figure 9, Counter-Based breaks down first, and then ASBA and finally AHBP. The results are quite intuitive – the more efficient the protocol, the better it works under heavy traffic scenarios.

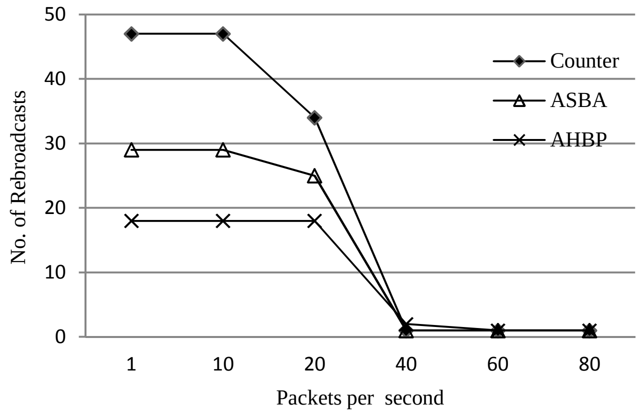

Figure 8: Number of re-broadcasts versus congestion in the network

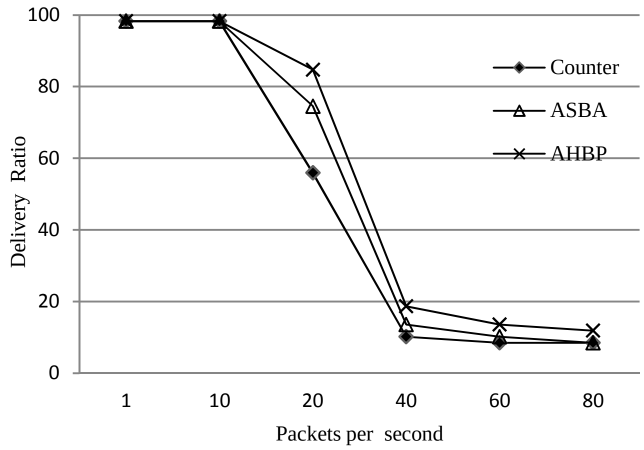

Figure 9: Delivery Ratio versus congestion in the network

VI. CONCLUSIONS

For infrastructure and resource starved rural villages, ad-hoc mobile phone networks can be used to create village-level telephony. This paper studied a new application for such networks, a village level community radio service. Any user in this network is equally empowered to broadcast audio content to the community. This study focused on the correct choice of the broadcast protocol to be used in such a network.

This paper identified desired characteristics of a MANET broadcasting protocol which can efficiently host a community radio service. The paper then described the performance analysis of selected protocols (Flooding, Counter-Based, ASBA and AHBP) from each of the categories under which we classified all available broadcasting techniques. We evaluated these protocols for a range of village-level ad-hoc network scenarios.

The community radio service that we envision needs a network wide broadcast protocol that is simple enough to deploy on basic mobile phones, efficient, robust to a rapidly changing network topology, adaptable to non-uniform node distribution, and should perform well in the face of heavy traffic. Our experiments allow us to identify suitable protocols for various network conditions. Flooding, the simplest of all the protocols is highly inefficient in dense networks and should only be used for very sparse networks. Counter-based can also be considered relatively simple, but our experiments show that it is also inefficient when the network density is high.

Both the neighbor-knowledge techniques we evaluated, ASBA and AHBP proved to be highly efficient, but each has its relative advantages. AHBP is more efficient in dense as well as congested networks but does not perform well under a changing network topology. ASBA on the other hand, adapts better to local network topology and works better when nodes are highly mobile, but is less robust under heavy traffic conditions. Hence, for very dense networks which are either static or where node movements are slow, AHBP would be a better choice. For example, in a small village, where users mostly commute by foot, AHBP would be a better choice. However, for networks where the topology changes rapidly, (for example, a more expansive village where motorized vehicles are prevalent) ASBA should be preferred over AHBP. Also, in a larger village, we would expect dense clusters of users in dwellings and around the main street of the village, and scattered users out in the fields and more remote areas. Since ASBA was shown to adapt better to local topology variations, we conclude that it might be a good broadcast protocol for the proposed community radio service.

However, the latency induced by ASBA's RAD functionality could affect the quality of the audio content. As future work we intend to design and evaluate modifications to the ASBA protocol to minimize the delay in broadcasting caused by the RAD component. We also plan to work on extensions to the AHBP protocol so that large changes in the neighborhood can be quickly identified and adapted to, leading to better performance under highly dynamic networks.

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