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*Year 2003*

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This article was originally published as: Lipman, J, Boustead, P, Chicharo, J & Judge, J, Resource aware information dissemination in ad hoc networks, The 11th IEEE International Conference on Networks (ICON2003), 28 September-1 October 2003, 591-596. Copyright IEEE 2003.

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# Resource Aware Information Dissemination in Ad hoc Networks

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**Abstract**—Information dissemination (flooding) forms an integral part of routing protocols, network management, service discovery and information collection (sensing). Given the broadcast nature of ad hoc network communications, information dissemination provides a challenging problem. This paper introduces Utility Based Flooding (UBF). UBF is a distributed optimised flooding mechanism for ad hoc networks that unlike existing optimised flooding algorithms is fully resource aware. Resource awareness is achieved by assigning a forwarding utility to neighbouring nodes to determine the desirability of a neighbouring node in continuing a flood. UBF is particularly applicable to ad hoc network environments composed of heterogeneous nodes that may have varying characteristics and constraints. In this paper, UBF is compared to existing flooding mechanisms in a constrained environment. Nodes are assigned varying degrees of remaining battery power and user based constraints that limit a node's benevolence based upon its remaining battery power. We show through simulation that UBF compared to Utility Based Multipoint Relay (UMPR) flooding, Multipoint Relay (MPR) flooding and Blind flooding significantly improves broadcast reachability over successive broadcasts, does not adversely affect performance and extends the lifetime of the network. UBF delivers packets to over 90% of nodes in the network for over 70 successive broadcasts. Blind flooding, UMPR and MPR are only able to achieve 42, 39 and 23 successive broadcasts respectively.

## I. INTRODUCTION

The advent of portable computers and wireless networking has led to large growth in portable computing due to the inherent flexibility offered. Most wireless networks are built around an infrastructure, where all communications go through base stations that act as gateways between the wireless and wired network. However, there may be situations in which it is impossible to construct such an infrastructure.

An ad hoc network is a collection of wireless mobile nodes forming a temporary network lacking the centralized administration or standard support services regularly available on conventional networks. Nodes in an ad hoc network may act as routers, forwarding packets. Ad hoc networks may undergo frequent changes in their physical topology. Mobile nodes may move, thereby changing their network location and link status. New nodes may unexpectedly join the network or existing nodes may unexpectedly leave, move out of range or switch off. Portions of the network may experience partitioning or merging, which is non-deterministic. An ad hoc network may operate in isolation or connected to a

fixed network (Internet) via a base station (gateway). Ad hoc networks are characterized by low bandwidth, high error rates, intermittent connectivity (partitioning), limited transmission range, device power constraints and limited processing capabilities.

In an ad hoc network, the goal of information dissemination is to maximize the availability of information either locally or globally throughout the ad hoc network while incurring minimal communications and device overheads. Given the nature of an ad hoc network, this poses a challenging problem. Any information dissemination mechanism must balance both the requirements and constraints of users, applications, devices and the ad hoc network. Constraints that need to be considered are: power, computation and communications. Excessive computation due to complicated flooding mechanisms, unnecessary full power broadcasts, reception and processing of unnecessary packets and medium contention all contribute to the drain on a mobile device's limited power source. Mobile processors have become increasingly powerful yet still have computational constraints, therefore the complexity of mechanisms employed should be considered. Wireless devices have limited communications bandwidth. Therefore to minimize medium contention, mechanisms should limit broadcast overlap or redundant broadcasts. Ad hoc networks may be employed in many aspects of daily life (home, office networks) as well as more specific tasks such as military applications, disaster recovery, conference events. In these networks there may be a need for information dissemination mechanisms that can account for any constraints or restrictions imposed on a device by the user. A user with a portable device may impose restrictions on the device forwarding packets or rebroadcasting if the device's battery power drops below a certain level. It is important that any information dissemination mechanism be able to modify its behaviour to account for these constraints.

The simplest mechanism for information dissemination within a network is flooding. Flooding is used by routing protocols such as AODV [1] and DSR [2] to obtain route information. The routing protocol OLSR [3] relies upon an optimized flooding mechanism, Multipoint Relay (MPR) [4],

to disseminate link state information efficiently. Flooding may also be used in network management to distribute state information or in zero start auto configuration. In blind flooding, a node broadcasts a packet, which is received by its surrounding neighbours. Each receiving neighbour then verifies that it has not broadcast the packet before. If not, then the packet is rebroadcast. Blind flooding terminates when all nodes have received and rebroadcast the packet. Blind flooding always chooses the shortest path, because it chooses every possible path in parallel. Therefore no other algorithm can produce a shorter delay. Of course this is not quite accurate in wireless networks where flooding may increase resource contention and hence impede its overall performance. A significant problem with blind flooding is the high overhead involved. One mechanism for minimizing this overhead is to reduce redundant broadcasts. In [5] flooding mechanisms which attempt to reduce redundant broadcasts are categorized as probabilistic based, area based and neighbour knowledge based. Probabilistic based approaches require an understanding of network topology to assign rebroadcast probabilities to nodes. Area based approaches assume nodes have a common transmission range, therefore nodes only rebroadcast if they provide sufficient additional coverage. Neighbour knowledge based approaches require that nodes make rebroadcast decisions based upon local neighbourhood knowledge obtained via beacon messages.

In this paper we introduce Utility Based Flooding (UBF). UBF is a distributed packet flooding mechanism that extends work done in Utility Based Multipoint Relay [6] flooding and Multipoint Relay flooding. UBF uses a utility based approach to provide a generic mechanism for determining the desirability of neighboring nodes in continuing a flood. UBF is resource aware in that it is aware of user based restriction imposed upon devices. UBF may be used in a heterogeneous environment where the forwarding utility is a function of both varying device characteristics (battery power, load), user defined characteristics (participation, benevolence) and neighbour characteristics. We show that the addition of resource awareness to MPR only marginally impacts performance in terms of energy consumption, transmitted and duplicate packets. More significantly, UBF as opposed to UMPR and MPR in a constrained environment is shown to more successfully utilize nodes in an ad hoc network for continuing floods thereby extending the lifespan of the ad hoc network and increase the total number of successive broadcasts.

This paper is organised as follows. Section 2 describes published mechanisms for flooding. Section 3 describes Utility Based Flooding. Section 4 provides a performance comparison and analysis. Section 5 concludes the paper.

## II. OPTIMIZED FLOODING IN AD HOC NETWORKS

In [7][8] the problems associated with blind flooding in ad hoc networks are identified and referred to as the

*broadcast storm problem*. It is identified through simulation and analysis that blind flooding is extremely costly and may result in redundant broadcasts, medium contention and packet collisions.

Multipoint Relay (MPR) flooding is a distributed flooding mechanism employed in the OLSR routing protocol for the dissemination of link state information. The mechanism aims to reduce the number of redundant retransmissions during flooding. The number of retransmitters is restricted to a small set of neighbor nodes unlike blind flooding. This set of nodes is minimized by efficiently selecting neighbors which provide one hop cover of the network area provided by the complete set of neighbors. These neighbors are the multipoint relays for a given node. The mechanism is distributed as each node must determine its own MPR set independent of other nodes. Finding the minimal MPR set is NP complete, however the authors propose the following algorithm for a node to choose its MPRs:

- 1) Find all 2 hop neighbors reachable from only one 1 hop neighbor. Assign the 1 hop neighbors as MPRs.
- 2) Determine the resultant cover set the set of 2 hop neighbors that will receive the packet from the current MPR set.
- 3) From the remaining 1 hop neighbors not in the MPR set, find the ones that cover the most 2 hop neighbors not in the coverage set.
- 4) Repeat from step 2 until all 2 hop neighbours are covered.

In addition to MPR, there has been significant work in optimised flooding mechanisms for ad hoc networks [9][10][11]. However, these mechanisms only attempt to limit problems associated with the broadcast storm problem. The heterogeneous nature and constraints imposed on mobile devices as discussed in this paper are not considered. Utility based Multipoint Relay (UMPR) flooding [6] is a distributed flooding mechanism that extends MPR and introduces a limited degree of resource awareness when selecting nodes capable of continuing a flood. UMPR assigns a forwarding utility to nodes in step 3 of the above MPR algorithm. This allows for 1 hop nodes that do not have unique 2 hop neighbours to be selected as relays based upon their forwarding utility. The forwarding utility used is a function of a neighbouring nodes remaining battery power and the total number of distinct neighbours that are not shared with other relays. The problem with the UMPR approach is that 1 hop nodes with distinct neighbours tend to dominate and therefore the use of a forwarding utility is limited. The Utility Based Flooding algorithm described in the next section avoids this problem by not performing step 1 of the MPR algorithm. Nodes are thus elected as relays based solely upon a forwarding utility that incorporates varying device characteristics and constraints. Thus only the most suitable nodes participate in continuing a flood.

### III. UTILITY BASED FLOODING (UBF)

UBF is a distributed utility based flooding mechanism that attempts to solve two problems associated with flooding in ad hoc networks. Firstly it attempts to minimize the broadcast storm problem by limiting rebroadcasting to only essential nodes in a similar fashion to MPR. Secondly, UBF assumes a heterogeneous ad hoc network in which nodes consist of varying inherent hardware and user defined characteristics. Hardware characteristics may be limited processing capabilities and limited battery life. User defined characteristics may be constraints that limit a device's participation or benevolence in supporting ad hoc network services (flooding and routing) based on a device's remaining internal battery power.

A user may allow a device to be attached to a reliable power source to fully participate in network activities. However, if the device is mobile and the battery power drops below a specified limit, the user may not wish the device to participate. Existing flooding mechanisms do not account for this type of behaviour and therefore their performance will be degraded in such a network. More importantly, as mobile devices have finite battery power, mechanisms such as MPR will only utilise nodes to continue a flood that provide an optimal broadcast and therefore will more quickly deplete these nodes. UBF, however, will adjust the selection of nodes to continue a flood based upon their utility. UBF is therefore able to distribute the load of flooding to the nodes most suited by calculating a forwarding utility for each neighboring node to determine its desirability as a forwarding node. In this paper, as an example, the forwarding utility is a function of a nodes remaining battery life, its benevolence and its neighbor utility.

A node using UBF generates a pool of 1 hop neighbors and a pool of 2 hop neighbors. All nodes associated with the previous broadcast and forwarding list are removed from the pools. 1 hop neighboring nodes with neighbours in the 2 hop pool are assigned a forwarding utility. An allocation then occurs, which adds the 1 hop node with the highest utility to the forwarding list and removes its neighbors from the 2 hop pool. The forwarding utility for the remaining nodes is then revised, thus taking account of the allocation. This continues until the pool is an empty set, the remaining 1 hop nodes are not added to the forwarding list therefore inhibiting them from rebroadcasting. The UBF algorithm is may be stated as:

- 1) Upon receiving a broadcast, determine all 1 hop and 2 hop neighbours that did not receive the previous broadcast.
- 2) Calculate a forwarding utility  $U_f$  for each 1 hop neighbour. Select the 1 hop neighbour with the highest utility, remove any 2 hop neighbours that will hear its broadcast and add the 1 hop neighbour to the relay list, removing it from the list of 1 hop neighbours.

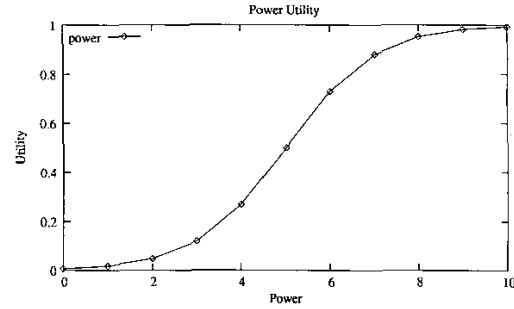


Fig. 1. Sigmoid Power Utility  $U_p$

- 3) Repeat from step 2 until all 2 hop neighbours are covered.

The UBF forwarding utility  $U_f$  (equation 1) used to select relays is resource aware. This is important as node's selected as relays must be capable of continuing a flood. Resource awareness in terms of a node's internal battery power is expressed in equation 2. Additionally, user based constraints of node participation are represented and described as benevolence ( $B$ ). Other utilities which account for link or node stability, device load or other user defined parameters may also be used.

$$U_f = BU_p U_n \quad (1)$$

$$U_p(i) = \frac{1}{1 + e^{-P_i + s}} \quad (2)$$

$$U_n(i) = \frac{\text{unallocated 2-hop neighbours of node } i}{\text{total 2-hop neighbours of node } i} \quad (3)$$

The utility  $U_p$  (equation 2) specifies the remaining internal power utility of a device. A sigmoid function as seen in figure 1 is used to determine the utility as it provides a good estimate of the required behaviour (low utility and slow change at low power; sharp change in utility at medium power; high utility and slow change at high power).  $P_i$  is the remaining internal battery power of a device and is mapped onto the sigmoid. To shift the sigmoid function accordingly,  $s$  is defined as half the range of  $P_i$ .

The neighbour utility  $U_n$  (equation 3) for a node  $i$  is equal to the number of unallocated nodes in the 2 hop pool that are neighbours of node  $i$  divided by the total number of neighbours of node  $i$ . Therefore node  $i$ 's utility will decrease as its shared neighbours are allocated to other relays. MPR in comparison only considers the total distinct 2 hop neighbors. In MPR, a 1 hop node with unique 2 hop neighbours is allocated any 2 hop neighbouring nodes that it may share with other relays. In UMPR [6] this important step in MPR is maintained, however it is problematic as

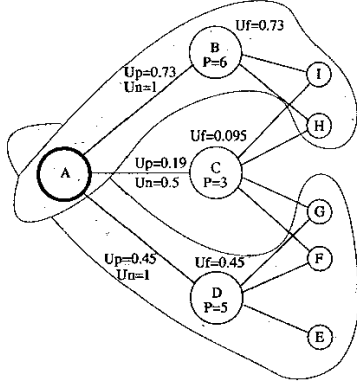


Fig. 2. Utility Based Flooding Example

it will allow these nodes to be exempt from the selection process based upon their forwarding utility and therefore reduces the ability of UMPR to fully utilize nodes based upon their utility. In this paper, UBF corrects this problem by calculating  $U_f$  for all 1 hop nodes. From the UBF algorithm, it can be seen that UBF recalculates the utilities of all 1 hop nodes after an allocation has occurred. Therefore nodes with unique neighbours will have a higher forwarding utility as the neighbour utility  $U_n$  ensures that a node with unique neighbours will have an increasing utility compared to 1 hop nodes with no unique 2 hop neighbours.

In UBF the following is assumed: Nodes maintain a list of neighboring nodes, which for a node  $i$  is denoted by  $N(i)$ . Beacon messages are broadcast periodically to inform neighbouring nodes of their existence. Neighbour information (remaining battery power and user based constraints) that may restrict a node's forwarding behaviour are attached to beacon messages. The list of nodes responsible for continuing a flood is attached to the broadcast packet. A pseudo code example of UBF is as follows:

**Algorithm UBF()**

1.  $P_1 \leftarrow$  1 hop neighbors
2.  $P_2 \leftarrow$  2 hop neighbors
3.  $i \leftarrow$  last node to broadcast
4.  $FL_i \leftarrow$  previous node forwarding list
5.  $P_1 \leftarrow P_1 - N(i) - \{i\}$
6.  $P_2 \leftarrow P_2 - N(i) - N(FL_i) - \{i\}$
7. **while**  $P_2 \neq \emptyset$
8.     **for each** node in  $P_1$
9.         Calculate its forwarding utility
- 10.
11.      $n \leftarrow$  highest utility node from  $P_1$
12.      $P_2 \leftarrow P_2 - N(n)$
13.      $FL_j \leftarrow FL_j + n$
14.      $P_1 \leftarrow P_1 - n$
15. **return**  $FL_j$

Figure 2 shows an example of UBF flooding with the following neighbour arrangement:  $N(A)=\{B,C,D\}$ ,

$N(B)=\{A,H,I\}$ ,  $N(C)=\{A,F,G,H,I\}$ ,  $N(D)=\{A,E,F,G\}$ . The broadcasting node A calculates a pool of 1 hop  $P_1=\{B,C,D\}$  and 2 hop neighbors  $P_2=\{E,F,G,H,I\}$ . Node A calculates forwarding utilities for the nodes in  $P_1$  as shown in figure 2. Nodes in  $P_2$  are allocated to the node in  $P_1$  with the highest utility. Node B has the highest forwarding utility, therefore nodes I and H are allocated to node B and removed from  $P_2$ . Node A then recalculates the forwarding utilities given the previous allocation. Node D is selected as its overall forwarding utility is higher than node C. Nodes E, F and G are allocated to node D and removed from  $P_2$  making it an empty set. The final forwarding list for node A is  $FL_A=\{B,D\}$ . If MPR had been used, node A would have allocated nodes C and D as forwarding nodes, despite node C's low internal battery power. Multiple floods from node A would then have depleted node C.

IV. RESULTS

A simulation was developed that generates a random topology of nodes within a 600 meter by 600 meter area. Nodes have a maximum transmission range of 100 meters. Time is divided into epochs. An ideal MAC layer is assumed. There is no medium contention nor hidden node scenario within the simulation as it is assumed that during an epoch all nodes can complete their transmission. The transmission medium is error free. A bidirectional link between two nodes is assumed upon reception of a beacon message.

A first order radio model [12] is assumed. In this model the first order radio dissipates  $E_{elec} = 50nJ/bit$  to run the circuitry of a transmitter or receiver and a further  $\epsilon_{amp} = 100pJ/(bit * m^2)$  for the transmitter amplifier. Equation 4 is used to calculate the costs of transmitting a  $k$  bit message a distance  $d$ . Equation 5 is used to calculate the costs of receiving a  $k$  bit message. The radios have power control and consume the minimal required energy to reach the intended recipients.

$$E_{Tx}(k, d) = E_{elec} * k + \epsilon_{amp} * k * d^2 \quad (4)$$

$$E_{Rx}(k) = E_{elec} * k \quad (5)$$

Nodes are initialized with randomly varying battery power between 0 joules and 2 joules of energy. A random node in the topology is selected as the initial node of a flood. To obtain confidence intervals, the simulation is executed 50 times starting with a different initial seed for each number of nodes. In each simulation run the simulation determines a topology, initiates a broadcast and waits for the broadcast to complete. Nodes have varying restrictions on their participation in the ad hoc network based upon their internal battery power. A node may be in one of either three states: (i) Depleted the node has ceased operation due to battery failure and therefore cannot participate in the network. (ii) Restricted the user has specified a minimal battery level below which the node will not participate in packet flooding, but may still use the

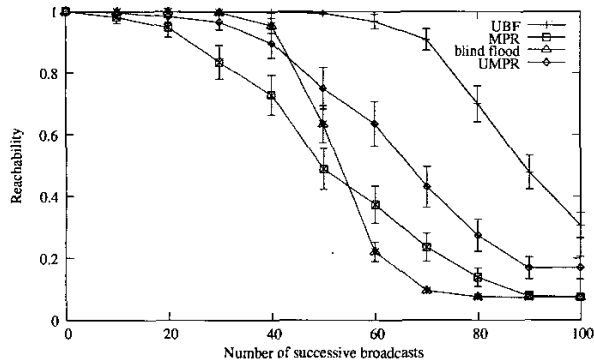


Fig. 3. Broadcast reachability over multiple broadcasts

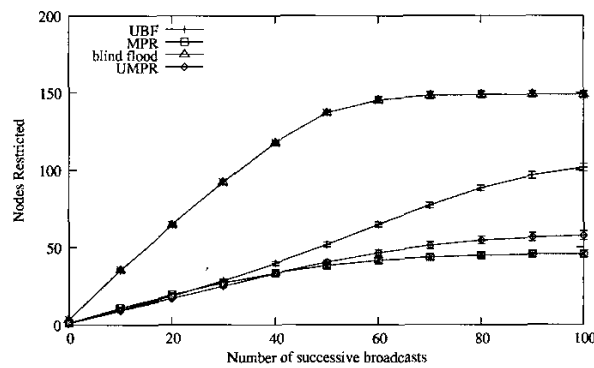


Fig. 4. Number of restricted nodes over multiple broadcasts

network and receive broadcast packets. (iii) Active the node participates in all operations of the ad hoc network and will rebroadcast and receive packets accordingly.

To determine the effectiveness of UBF at selecting suitable nodes, thereby extending the life of the network, the simulation performs 100 successive broadcasts and the total number of nodes reached by a broadcast is recorded. The results are shown in figures 3 and 4.

Figure 3 shows that UBF after 70 successive broadcasts is able to reach above 90% of nodes in the network. Blind flooding achieves 42 successive broadcasts, UMPR achieves 39 and MPR achieves 23. These results show a forwarding utility that is a function of a nodes remaining battery power and user constraints allows for significant improvements in broadcast reachability over successive broadcasts. UBF is able to direct the responsibility of flooding to those nodes with greater battery power as in figure 2 and account for the constraints imposed upon nodes. UMPR is only partially able to do this, while MPR and blind flooding are unable to do this.

The ability to direct the responsibility of flooding to nodes most suited allows for the load of flooding to be shared by all nodes, thus increasing the use all nodes rather than just

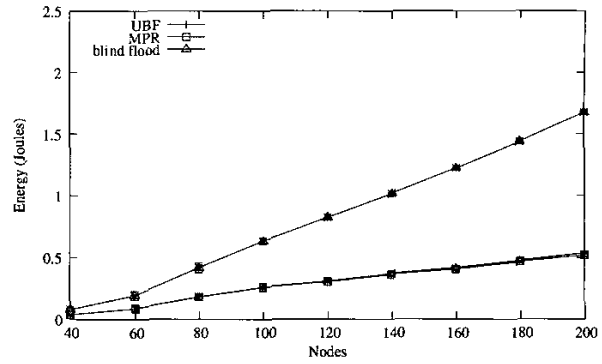


Fig. 5. Power Usage per Completed Broadcasts vs Number of Nodes

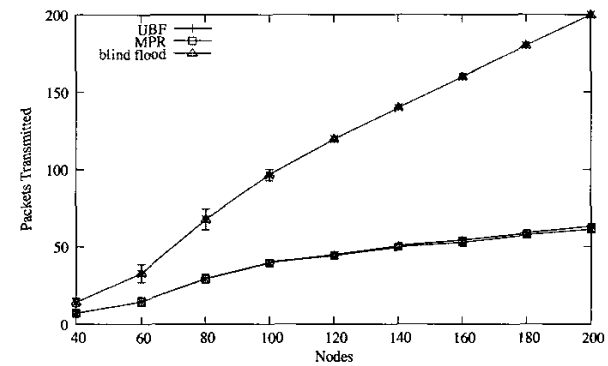


Fig. 6. Packets Transmitted per Completed Broadcasts vs Number of Nodes

those optimal nodes (relays), which may be running low on battery power or be constrained. Blind flooding's brute force approach results in all capable nodes participating in a flood, thus increasing the possibility of a flood progressing even in the presence of restricted nodes. However, in figure 3, blind flooding shows a rapid decrease in broadcast reachability between 40 and 60 broadcasts. This decrease in reachability is a direct result of the increased number of restricted nodes (75%) as shown in figure 4. MPR and UMPR however do not show a significant increase in restricted nodes. This is because the number of nodes receiving broadcasts is significantly lower than that of UBF or blind flooding. In the case of UMPR, it shows that UMPR is unable to fully utilize all nodes. This is because UMPR allocates 1 hop neighbour nodes with unique 2 hop nodes as relays and does not determine their suitability to continuing a flood. Because UBF attempts to distribute the load of flooding, the number of restricted nodes is higher than MPR, but lower than blind flooding with its brute force approach. At the same time, UBF is able to maintain a much higher broadcast reachability than either UMPR, MPR or blind flooding due to its ability to select only those nodes most suitable to continuing the flood.

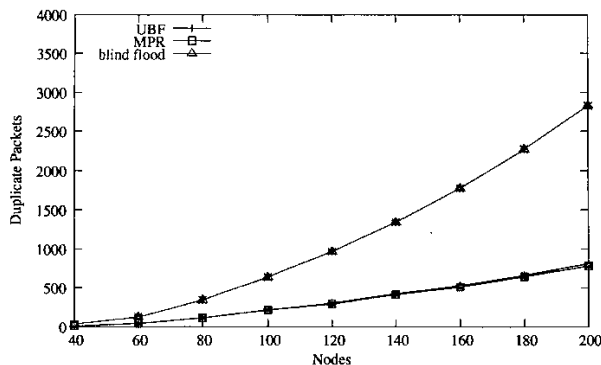


Fig. 7. Duplicate Packets per Completed Broadcasts vs Number of Nodes

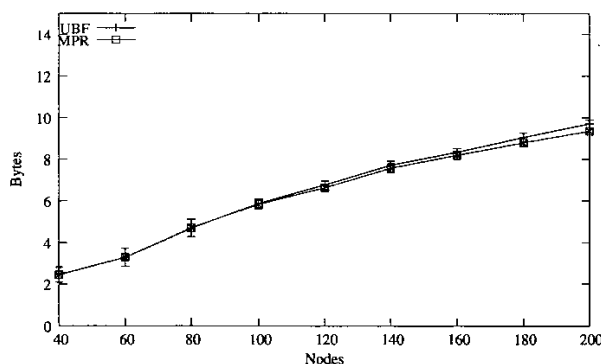


Fig. 8. Overhead vs Number of Nodes

To determine the performance (energy consumption, transmitted and duplicate packets) of UBF we have chosen to compare it with both MPR and blind flooding as show in figures 5, 6, 7 and 8. The figures show the results obtained for a single broadcast over increasing node densities. The comparison with MPR is to show that there is a minimal increase in overhead given utility based forwarding decisions. We do not display UMPR as the results are very similar to MPR. From the figures it can be seen that that UBF and MPR have equivalent performance providing significant reductions for a completed broadcast in terms of power consumption, packets transmitted and duplicate packets received over blind flooding.

## V. CONCLUSIONS

In this paper we have introduced Utility Based Flooding (UBF), an optimised, resource aware and distributed flooding mechanism for information dissemination in ad hoc networks comprised of heterogeneous nodes. Nodes are heterogeneous in that they have varying characteristics such as internal battery power and user based constraints which inhibit their interaction in the ad hoc network. UBF extends UMPR and MPR by requiring that the selection of all relays be based upon their forwarding utility. The use of utilities provides a generic

mechanism for determining the desirability of neighboring nodes in continuing a flood. The forwarding utility used in this paper is a function of a device's power utility, neighbour utility and benevolence. UBF is compared to existing flooding mechanisms in a constrained environment. Nodes are assigned varying degrees of remaining battery power and user based constraints that limit a nodes benevolence based upon its remaining battery power. UBF through simulation is compared to Utility Based Multipoint Relay flooding, Multipoint Relay flooding and Blind flooding. UBF significantly improves broadcast reachability over successive broadcasts, does not adversely affect performance and extends the lifetime of the network. UBF delivers packets to over 90% of the network for over 70 successive broadcasts. Blind flooding, UMPR and MPR are only able achieve 42, 39 and 23 successive broadcasts respectively.

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