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Message Routing with Counting Bloom Filter for Name-Based Home Ad Hoc Networks

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Abstract - As future home appliances will have many useful built-in functions, a communication network that allows a user to access these built-in functions and to control the appliances is highly desirable. If the home appliances are fitted with a wireless communication module, a wireless ad hoc network can be used to easily connect the appliances. For ease of use the nodes are given names such as "living room TV", "kitchen oven" etc. for identification. This paper proposes the use of counting bloom filter as a routing table for message routing in a name-based home ad hoc network and also discusses the performance of the proposed algorithms via simulation.

Keywords - *Ad hoc network, Home network, Name-Based addressing and routing, Bloom filter*

1. Introduction

Advances in technology have enabled wireless capabilities to be incorporated in to many aspects of daily life such as households. In recent times the number of wireless devices in the home environment has also risen. This trend continues to introduce wireless capabilities to household appliances and sensors which monitor aspects such as safety as well. Most of the devices in a household remain at one place in the house such as television, refrigerator etc. However some devices such as smart phones, laptops etc. maybe moved around the household with the user. Creating a network of wireless devices at home will greatly assist the users to control and monitor their household environment.

Today most new household devices are fitted with technologies such as Wi-Fi, but there are some devices with different short range technologies such as Bluetooth or infrared. Smaller sensor like devices may be powered by a limited power source. If the Wi-Fi access point is at a distance, transmitting at high power will reduce the lifetime of devices that use limited power sources. It is possible that a single Wi-Fi access point may not cover the entire household due to obstacles such as walls. The dependence on central access point(s) also has the risk of entire (partial) network failure. The home environment may consist of various appliances with many different functions and capabilities. Hence the heterogeneity of the home appliances need to be considered when forming a network as the transmission distance, processing power and memory etc. of the appliances and sensors may vary.

This paper proposes a futuristic home environment where wireless enabled household appliances and sensors are connected via an ad hoc network. Long-range networks such as Wi-Fi access points are also considered as being a part of the entire network. This network will enable users to access and control home appliances and sensors from anywhere in the network through other appliances or sensors (hereafter referred as nodes). Such a network is cost effective as no extra equipment is required and it also supports the heterogeneity of nodes.

The nodes in the network are identified using everyday names such as "Living room TV, Kitchen light" etc. to increase usability. An IP based solution with DNS is also possible, however it requires the user to initially map the description or keywords to IP addresses when the network is setup or when a new device is added or removed from the house. Such a solution requires higher technical knowledge and additional hardware may also be required.

The proposed system uses a much simpler approach. For example, during setup of the home network a user walks to a location in his household with a device which has a user interface such as a smart-phone or laptop. Through this device the user is able to see a list of compatible wireless devices whose default names are given by the manufacturer. The user may also change some node names as preferred. Then the user will assign a common location name through his device to multiple nodes in that location by selecting and grouping them from the list. The user will follow the same simple steps in other locations in the house to setup the home network. Also nodes added later will join the network automatically without any user intervention. Such an easily setup home network will provide convenience and support life in an ordinary house.

2. Related Work

A Bloom filter [1] based routing protocol on a flat ad hoc network has been proposed by Osano et al. [2] where all nodes require equal capabilities. Nodes proactively request routing data from neighbor nodes to store the network topology up to two hops as well as to build a bloom filter with hashed values of all node IDs that are reachable through a single link. But the nodes are required to store the sent packet details in order to back track a message incase it was sent through a wrong link due to false positives caused by the bloom filters.

A clustered ad hoc network is created in CBRP [3] where all nodes use three conceptual data structures. The *Neighbor Table* (NT) is used to store their bidirectionally linked neighbor nodes. A *Cluster Head* (CH) node is selected for each cluster of nodes to provide the routing for all the member nodes in that cluster. The *Cluster Adjacency Table* (CAT) is used to store the neighboring CH nodes. Also a *Two-hop Topology Database* (TDb) is built using periodical broadcasts of NT that stores network topology information up to two-hops away. A form of source routing is used in CBRP as well as by Johnson [4] in order to discover routes.

Routing overhead increases as the number of nodes increase, and the route must be discovered before any data is sent. Also Johnson [4] uses periodic routing updates to maintain the routes. Krishna et al. [5] requires that all the nodes have similar high performance capabilities to build a routing table and nodes use Dijkstra's algorithm so that each node could find a shortest path to a destination.

A publisher/subscriber communication model for wireless mobile ad hoc networks is described by Petrovic et al. [6]. But in this proposal the amount of data kept for routing purpose is high, as much as five table structures. A similar approach is also used by Meisel et al. [7], but uses "Named-Data" where data name prefixes are flooded and cached in the network. Data requests are also flooded in the network and any node with the requested data may respond.

The data requester can select a suitable responder to receive the data. Intermediate nodes may cache the data itself for other requests. In both Petrovic et al. [6] and Meisel et al. [7] when the publishers, subscribers and types of events are large, the caching requirement of the nodes also becomes high.

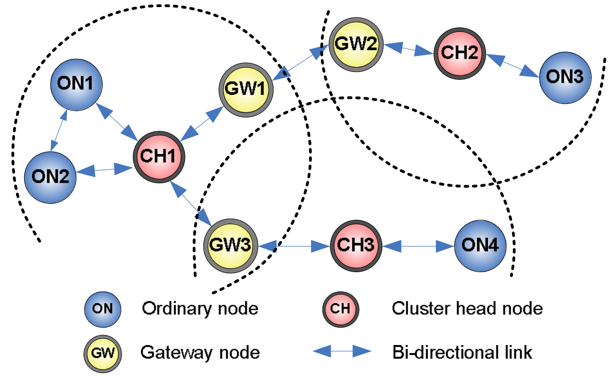

Fig. 1 A sample network

3. Network Environment

A cluster-based network is implemented in the home environment as appliances and sensors can be considered as a group depending on their location in the house, such as dining room, kitchen and bedroom etc. A cluster-based approach also has advantages such as lower control overhead [3], [5].

A loop free network [9] (Fig. 1) is formed where the nodes in the network become a CH, a Gateway (GW), or an Ordinary Node (ON) after joining the network [8].

3.1 Node Naming

It is assumed that a default name is given to every appliance or sensor by the manufacturer such as the model number etc. The user may also modify these names for easier identification such as television, smoke sensor etc. considering the type or functionality of the appliance or sensor where the names may also be duplicated. A few nodes in each location of the house are given names including their location in the home environment at the initiation of the network.

The rest of the nodes or new comer nodes will discover its location name from its neighboring nodes depending on the reception signal strength [9]. The location name is given to the nodes as a prefix to its fixed name such as *kitchen oven, living room light, bedroom television* etc. This approach closely relates to class-based identifiers [10]. The location name should also be assigned as uniquely as possible to avoid messages being forwarded in the wrong path.

4. Organization of Clusters and Network

This section introduces the conceptual data structures and types of messages used in this paper. The formation of clusters and the network are also discussed.

4.1 Conceptual Data Structures

Conceptual data structures are used to assist the cluster and network formation as well as routing. The NT (Table 1) is modified to include a *Priority* and the reception *Signal strength* fields of the neighbor's message. Also the algorithms used here require only CH and GW nodes to store their neighboring clusters in CAT (Table 2). The NT and CAT entries also have expiration times. The message arrival time is measured by a node's internal clock and kept as a time stamp with each entry.

4.2 Types of Messages

There are 2 types of messages used in the network. *Hello* and *Reply* Control messages are used to identify neighbors and configure the network. The *Update* control message is used to update the routing information of nodes. Control message format is given in Table 3. Depending on the available internal information, the NT, CAT and CBF/CBFT fields maybe included or omitted in control messages. *Data* messages are sent after the formation of the network. The destination node also sends an *Acknowledgement* (Ack) message back to the source node. For a data source/destination pair, each Data/Ack message also uses sequence numbers for identification. Data/Ack messages format is given in Table 4.

4.3 Formation of Clusters and the Network

Two nodes are considered to have a connection when there is a bi-directional link between them. The clusters are formed by connected nodes based on location name as a common property. Clustering strategies such as lowest ID [11], highest connectivity [11], [12] does not consider the available resources of the node. This paper uses a priority based scheme [9] where a higher priority means having higher processing, memory, transmission power and lower power consumption etc. In this priority scheme, the node with highest priority in a location becomes the CH and the rest of the nodes become ONs.

After the formation of the individual clusters, the CH nodes discover their neighboring clusters to form a network. Two neighboring clusters can establish a bidirectional link through one or two ON nodes. Any node from a particular cluster is able to identify whether another node is from the same cluster or not, based on the

Table 1: Neighbor Table

Field	*Description*
Name	Name of the node (including location)
Status	Status of the node (ON/GW/CH)
Time stamp	Last message received time
Priority	Priority of the node
Signal strength	Reception signal strength

Table 2: Cluster Adjacency Table

Field	*Description*
CH name	Neighbor CH node name
GW name	First hop GW node name to this cluster
Time stamp	Last Hello received time from first hop GW node

Table 3: Control message format

Field	*Description*
Name	Name of the sender
Status	Status of the sender
Destination	Message destination node name
Description	Type of message
Priority	Priority of the sender node
NT	NT of the sender
CAT	CAT of the sender (CH/GW nodes)
CBF/CBFT	CBF/CBFT of the sender (CH/GW nodes)

Table 4: Data/Ack message format

Field	*Description*
Name	Name of the sender
Seq. No.	Message sequence number
Description	Type of message
Destination	Message destination name
Prev_Sender	Previous sender's name
Nxt_Receiver	Next receiving node's name
TTL	Available number of hops
Data	Data carried by the message (only for Data message)

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location name of the other node. This difference in location names of the two clusters are used to identify each cluster separately [9]. These ON node(s) in the connection path between the two clusters will become GW(s) when the two clusters are connected. The identification of the GW nodes forms the network.

In this network a node is aware of its one-hop neighborhood with the use of NT. GW and CH nodes are also aware of the neighboring clusters and how to reach them. In order for a GW/CH to have routing information about the nodes beyond the range covered by NT and CAT, this paper propose the use of a bloom filter.

5. Routing Protocol with Bloom Filter*[1]

This section will introduce the bloom filter and its usage for message routing.

5.1 Use of Bloom Filter

The home environment also consists of resource restricted nodes such as a battery powered smoke-sensor as well as highly resourceful nodes such as laptops. The communication protocol for such an environment must be able to accommodate the resource restricted nodes such that it does not cause a bottle neck in the network and ensure limited use of resources. This in return ensures network survivability as well as lower power consumption for a greener network.

A bloom filter is an array of bits which contain the hashed values of keys. It allows storage of a large key with only a few bits. A set $S = \{s_1, s_2, \ldots, s_n\}$ of n elements are each hashed using k independent hash functions ($h_1, h_2, \ldots, h_k$). The hashed value of each element s in S, $h_i(s)$, (i=1, 2,…,k) is stored in a bit array of size m, where a bit is set to 1 for insertion. The existence of an element x in the bloom filter can be verified by checking whether all $h_i(x)$, (i=1, 2,…,k) bits are 1.

But due to the size restriction of the bloom filter the hashed values can overlap (*hashing collision*) and produce a false match (*false positive*). The probability of a false positive is determined approximately as [1],

$$P_{fp} \approx (1 - e^{-kn/m})^k \, . \tag{1}$$

But if the false positives can be minimized by selecting proper k, n and m values, the efficient space usage of the bloom filter can be utilized. A minimum false positive rate (P_{FP}) is calculated as [16],

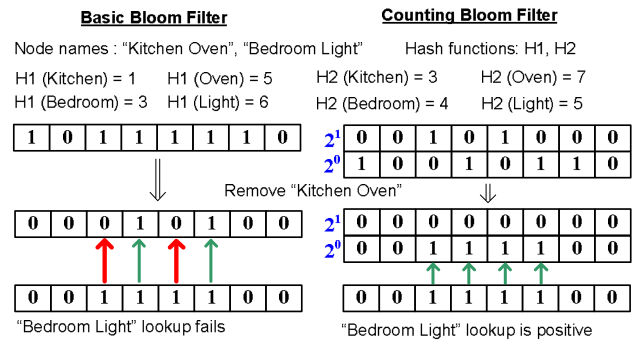

Fig.2 A basic bloom filter and a CBF with a length of 8 bits and use 2 hash functions. CBF has a bucket size of 2 bits. Removal of a key from basic bloom filter can cause a false negative. Removal of a key from CBF does not cause a false negative.

Table 5: CBF Table

Field	*Description*
Name	Name of first hop CH/GW node in the direction of CBF
CBF	CBF associated with the link

$$P_{FP} = 2^{-k} \, , \tag{2}$$

when the number of hashing functions are,

$$k = \ln 2(m/n) \, . \tag{3}$$

When mobile nodes are also present in the network, the information in NT, CAT and bloom filter needs to be modified to reflect the topology changes. When entries are removed from a bloom filter it can cause *false negatives* which causes message routing failures. A *Counting Bloom Filter* (CBF) [13] is used in this paper in order to minimize the effect of false negatives (Fig. 2). Instead of a single bit in each position of the array, CBF uses a *bucket* (higher number of bits) at each position which enables it to count the number of times a bit position is set to 1. This paper uses a bucket size of 4-bits which has been proven to be sufficient for most applications and that the probability of overflow is minuscule [13]. The probability of a false positive for CBF is also determined by (1) as the membership query based on standard bloom filter also hold for the membership query based on CBF [15].

*[1] A preliminary investigation and results were published in [20] by the same authors.

During the formation of clusters and the network, control messages are used to populate the NT and CAT. When a GW/CH node *n* receives a control message from another GW/CH with populated NT/CAT, *n* inserts any non-neighbor NT entries and non-adjacent cluster entries to a CBF assigned to that link. A CBF will be allocated to every link to a GW/CH node that has routing information beyond what is kept by *n*'s own NT and CAT. The CBFs are stored in another conceptual data structure called CBF Table (CBFT) (Table 5). When *n* sends a control message through a particular link *l*, it merges all CBFs except the CBF in the direction of *l* using logical OR function (Fig. 3). When a node receives this control message the received CBF is merged with the node's CBF for that link using a logical OR function. When a node's routing information is changed from a received Reply message, it will send an Update message including CBFT which is received by all GW/CH nodes in transmission range. Upon receiving an Update message a node will remove the CBF associated with the link between the sender and itself from the received CBFT. Then it will perform a logical OR operation with all other CBFs in the received CBFT with its own CBF associated with the link between the sender and itself. The following Algorithm-1 summarizes this procedure.

Algorithm-1

1. Discover neighbors (populate NT) using periodical Hello messages and corresponding Reply messages.
2. Determine the location name of nodes based on the received signal strength from neighbors and decide the role of the nodes as ON/CH.
3. Discover GW nodes between the clusters using difference of location name and populate CAT.
4. If sender and receiver of a Reply message are either GW/CH, add all non-neighbor NT entries and non-adjacent cluster entries to a dedicated CBF for the sender's link.
5. If a CBF is also present in the Reply message, perform a logical "OR" operation with the dedicated CBF for the sender's link.
6. If routing information in either NT/CAT/CBFT changed, send Update message.
7. If an Update message is received, perform a logical OR operation with the CBF for the sender's link with all CBFs in the received CBFT, except the CBF associated with this node.

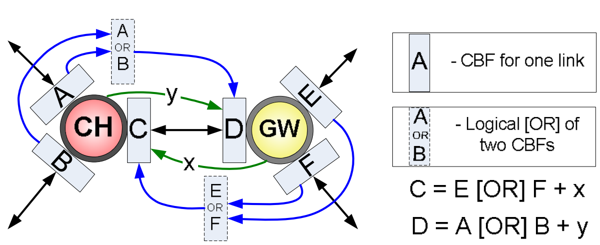

Fig.3 A CBF contains the information of all other CBFs of the neighbor GW/CH except the CBF in the node's link to the neighbor. It also inserts any non-neighbor NT entries and non-adjacent cluster entries (x, y).

When mobile nodes are present in the network, the routing information must be kept updated in order to deliver messages accurately. Therefore the NT and CAT entries need an expiration time to reflect network topology changes. When a new neighbor node (n_1) is

Algorithm-2

1. Sender node will look for complete destination in NT. If found forward to destination.
2. If sender is an ON, and destination is not found forward the Data message to home CH node.
3. Intermediate CH/GW nodes search for complete destination in their NT/CAT. If found forward to appropriate next receiver node.
4. If intermediate CH/GW node is unable to find destination in own NT/CAT, look for the hashed values of the destination name in CBFT and forward to the corresponding link if a matching CBF is found.
5. If hashed destination is found in multiple CBFs forward the message without a specific next receiver name.
6. Drop the message if matching hash values are not

discovered, a node looks for the matching hash values in CBFT. If a match is found in one of the CBFs (C_1), it removes the hash values of n_1 from C_1 and sends an Update message only through the link associated with C_1. This Update message propagates the whereabouts of n_1 to the previous location of n_1. If multiple matches for n_1 are found in CBFs, an Update message is sent without a specific next receiver to notify all other nodes.

A mobile node also changes its location name when it moves from one location to another. A node can detect its whereabouts by comparing the signal strength of its neighbors and decide the best location name for itself [9]. A mobile node also notifies the other communicating party of its new name to maintain communication.

5.2 Routing the Data Messages

The population of NT, CAT and CBFT marks the initialization of the network. At this point Data messages can be sent to any destination without any route discovery procedures as summarized in Algorithm-2. This algorithm looks for the destination name in the NT and CAT. If unsuccessful it looks for the hashed destination name in the CBFT.

In step 5 of the Algorithm-2, finding the hashed value of the destination in multiple CBFs implies that there is a possibility that one of the CBFs is producing a false positive. This means that a node must send a data message without specifying the next receiver node, which will result in all CH/GW nodes handling the message. Node(s) in the incorrect path(s) will drop the message after wastefully consuming its resources. Therefore in order to save resources the false positives must be reduced. Increasing the CBF (memory) size will also reduce the false positives however it also increases resource usage.

The node naming method used here allows the separation of the name as <location name> and <device name>. In a clustered environment the <location name> is a common prefix to multiple nodes. The device name itself may be duplicated in the home environment as some nodes might be given the same device name such as lights. We will use this inherent attribute of the home network and separate <location name> and <device name> of a node before inserting it into a CBF. A node will also check its targeted CBF for membership of the new candidate entry before insertion. If the membership is true, the candidate entry will not be inserted. This implies that only a fewer number of entries are required to be stored in CBF and that a node require less CBF memory to store the entries and achieve an optimal false positive rate. In a network with c number of clusters and d number of unique device names, the false positive rate can be represented as,

$$(1) => \quad P_{fp} \approx (1 - e^{-k(c+d)/m})^k \,. \qquad (4)$$

During data communication, nodes that receive the Data or Ack messages directly from the source or destination nodes will continue to send Hello messages and refresh their routing information (NT, CAT entries expire periodically). This allows the mobile nodes to recognize its whereabouts accurately and identify their location name or status. The CH and GW nodes in the forwarding path identify the previous sender node from the Prev_Sender field of the Data/Ack message. This enables the nodes to update time stamp of NT entries of forwarding neighbors to maintain the forwarding path. Nodes that do not hear any Data/Ack messages directly from the source or destination for certain duration, stops sending Hello messages and their NT/CAT entries will not expire.

When a node sends a Data message, the intermediate nodes forward it according to the available routing information. When the Data message is received by a node N that has the destination name in its NT, N will forward the message and wait for an Ack message from the destination node. If the destination node is still in the last known location, it will receive the message and send an Ack message back to N. Receiving the Ack message N will realize that the destination node is within its reach and the Ack message is forwarded back to the sender and also the NT time stamps of GW and CH nodes of the forwarding path becomes renewed by using Prev_Sender field of the Data/Ack messages. Incase where N does not receive an Ack message within certain duration, an Improved Blocking Expanding Ring Search Plus [14] is initiated by N to find the destination.

6. Evaluation

The evaluation of the proposed routing scheme and the effect of false positives on communication overhead were measured through simulation. The simulation environment was a flat surface of 100×100 units where 100 nodes were located. The nodes are placed randomly in the simulation environment for each simulation such that random topologies are formed with random number of clusters and random number of nodes in each cluster to represent different households. Each node is given random transmission distances (1, 2, 3 units) and priorities (1~10). The location names are also given to a random number of nodes (1~5) at each cluster to represent the user's contribution in location naming.

Mobile nodes are chosen as both the source and destination for data communication and they are paired randomly. All mobile source nodes send a Data message every time tick (TT) of the simulation clock which allows it to send and receive Data even during transition between clusters. The simulation duration is 10000 TTs. The speed of mobile nodes are between 0.1~1 unit/TT (If the maximum walking speed is considered as 1m/s, the mobile speed range can be interpreted as 0.1~1m/s). The validity period of NT, CAT entries are also fixed at 10TTs and the Hello messages rate is set as 9TTs. Also unique location names are used throughout the simulations. The bucket size is fixed as 4 bits but the size of CBF is varied.

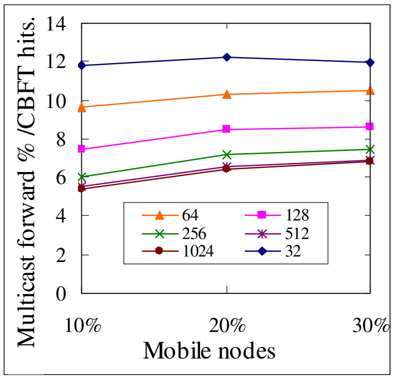

Fig. 4 Multicast forwarding % per CBFT hits Vs Mobile nodes

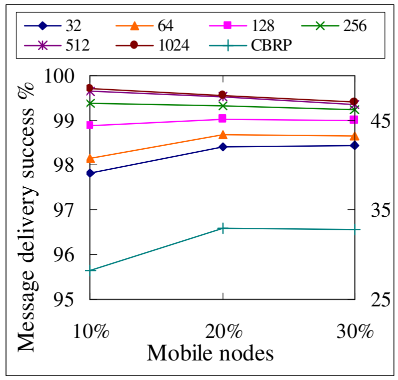

Fig. 5 Data message delivery success % Vs Mobile nodes

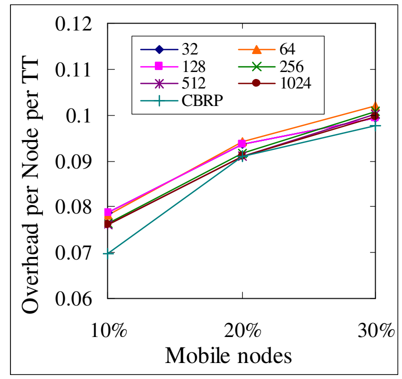

Fig. 6 Routing message overhead per node per TT Vs Mobile nodes

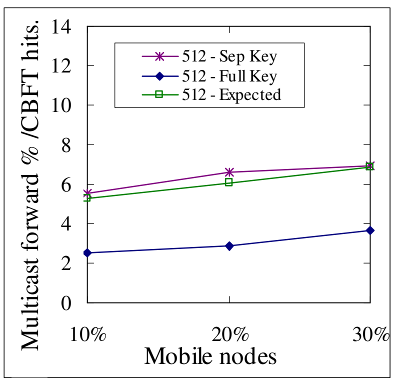

Fig. 7 Multicast forwarding % per CBFT hits Vs Mobile nodes

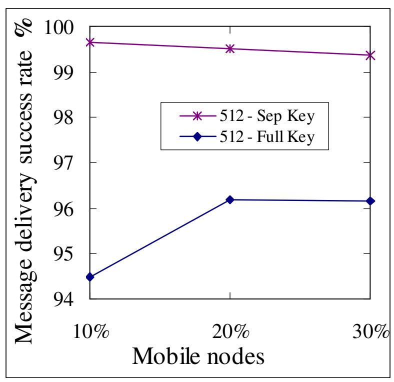

Fig. 8 Data message delivery success % Vs Mobile nodes

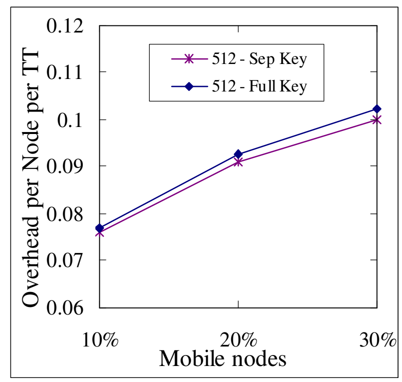

Fig. 9 Routing message overhead per node per TT Vs Mobile nodes

The routing scheme is simulated in multiple topologically random networks and the average of the results is presented.

When routing the Data messages a CH/GW node may search for the hashed values of the destination in the CBFT. The outcome of this search may be multiple CBFs providing a positive result, some of which are due to false positives. In this case the node decides to forward the Data message without a specific next receiver (termed *multicast forward*). Fig. 4 shows the average percentage of resulting multicast forwarding against the percentage of mobile nodes in the network when the size of CBF was varied. However a multicast forwarding also means that at least on of the receiver nodes should forward the message and the rest of the nodes would drop it. Fig. 4 shows that an increase in the CBF size reduces the overhead of multicast forwarding and it also provides an indication of the false positive rate. Fig. 5 shows the Data message delivery success rate of the proposed scheme. For comparison, CBRP [3] which also uses three conceptual Data structures of which two are the same (NT, CAT) is also used. The proposed protocol will use the CBFT while CBRP will use the TDb. Fig. 5 also shows that increase in CBF size results in better message delivery success. However even with unlimited TDb size CBRP only showed marginal success rate (Plotted on Fig. 5 right side Y-axis). Fig. 6 shows an indication of the number of control messages (Overhead) used by nodes to reconfigure the network topology due to mobility of nodes. Both CBRP and the proposed scheme required similar number of control messages for topology reconfiguration and the CBF size variation has no significant effect.

The simulation was also extended to compare the performance of using the complete name i.e. <location name + device name> as a single key when inserting to a CBF. Fig. 7 shows that the percentage of resulting message multicast forwarding are lower when using the complete name (Full Key) compared with separately (Sep Key) inserting <location name> and <device name> to a CBF. The separate insertion method may also give a match for combination of any two keywords which make a complete node name even though such a node may not exist. But insertion of complete node name to a CBF as one key will only give a match for the exact name resulting in a lower multicast forwarding percentage.

However the resulting message delivery success rate (Fig. 8) is lower than separate insertion. The network reconfiguration control message overhead (Fig. 9) which also includes routing updates also did not show significant differences between these two strategies. This comparison shows that separately inserting the <location> and <device name> yields better result with a tradeoff with slightly higher multicast forwarding rates.

When the CBF size is increased from 512 to 1024 the increase in success rate (Fig. 5) and the decrease in multicast forwarding overhead (Fig. 4) is insignificant. It shows that a CBF size of 512 is sufficient for the current network environment of 100 nodes. The expected false positive probability percentage (Fig. 7) was calculated with Eq. (4) using the average number of CBF entries experienced by the nodes as the number of mobile nodes is increased. The average number of CBF entries showed an increase from ~80 to ~90 entries as the mobility of nodes increased. The total number of keywords remained less than the number of nodes in the network (i.e. 100) due to the use of common <device> names for network nodes. Also the multicast forwarding seen in the simulation results closely correspond to the analytically expected false positive probability values.

7. Conclusion

This paper investigates the possibility of implementing a routing protocol using a counting bloom filter for a cluster-based ad hoc network with a name-based addressing scheme. The paper describes the reasoning and method of using the counting bloom filter as a routing cache. A performance comparison with CBRP on equal resources showed that the proposed scheme shows preferable results.

This research will continue to investigate the possibility of network expansion to cover a larger expanse to construct a network of home networks. A larger expanse would require a new naming scheme which has a higher order of hierarchy. This naming structure should also reflect the hierarchy of the network's topological structure such as a sub-cluster within a much larger generalized super cluster and so forth. As the number of nodes in such a network would be very high a bloom filter would also require a very large size to keep an optimal false positive ratio. Here it is possible to use any one from a multitude of improved versions of bloom filters which achieve better space savings and higher accuracy [17][18][19] rather than a basic CBF. Also in a name-based environment the intermediate message forwarding nodes need not know the entire network topology as long as there is sufficient routing information to deliver the messages to the next hop. In a hierarchical topology a node would only require the routing information to reach its neighbors and sub or super cluster. This approach would drastically reduce the number of entries to a bloom filter which in turn also reduces the bloom filter size requirements.

References

[1] Burton H. Bloom. 1970. Space/time trade-offs in hash coding with allowable errors. Commun. ACM 13, 7 (July 1970), 422-426.

[2] Osano, T.; Uchida, Y.; Ishikawa, N., "Routing Protocol Using Bloom Filters for Mobile Ad Hoc Networks," Mobile Ad-hoc and Sensor Networks, 2008. MSN 2008. The 4th Int. Conference on , vol., no., pp.89,94, 10-12 Dec. 2008.

[3] Mingliang Jiang, Jinyang Li, and Y.C. Tay. Cluster based routing protocol, (CBRP). draft-ietf-manet-cbrp-spec-01.txt, Internet draft, August 1999.

[4] Johnson, D.B.;, "Routing in ad hoc networks of mobile hosts," Mobile Computing Systems and Applications (WMCSA), pp.158-163, 8-9 Dec. 1994.

[5] P. Krishna, N.H. Vaidya, M. Chatterjee and D.K. Pradhan. "A cluster-based approach for routing in dynamic networks". ACM SIGCOMM Comp. Commun. Review 27:49-65, 1997.

[6] M. Petorvic, V. Muthusamy, H.Jacobsen, "Content-Based Routing in Mobile Ad Hoc Networks", IEEE MobiQuitous, 2005.

[7] M. Meisel, V. Pappas and L. Zhang; "Ad hoc networking via named-data" MobiArch '10, Proc. of the 5th ACM intl. workshop, pp 3-8, 978-1-4503-0143-5.

[8] M.Gerla, J.T-C. Tsai, "Multicluster, Mobile, Multimedia radio network". ACM- Baltzer Journal of Wireless Networks, 1995.

[9] Vidanagama, T.N.; Nakazato, H.; "Name-Based Message Forwarding for Home Ad hoc Networks", *Journal of Wireless Networking and Communications*, Vol.3, No.4, Oct. 2013.

[10] Shah, R.C.; Rabaey, J.M., "Energy aware routing for low energy ad hoc sensor networks," Wireless Communications and Networking Conference (WCNC), IEEE , vol.1, no., pp.350,355 vol.1, 17-21 Mar 2002.

[11] A. Ephremides, J.E. Wieselthier, D.J. Baker,; A design concept for reliable mobile radio networks with frequency hopping signaling, Proc. of IEEE, 75(1) (1987), pp.56~73.

[12] A. K. Prakah, "Selecting routers in ad-hoc wireless networks, Proc. of SBT/IEEE ITS (1994).

[13] Li Fan, Pei Cao, Jussara Almeida, and Andrei Z. Broder. 2000. Summary cache: a scalable wide-area web cache sharing protocol. IEEE/ACM Trans. Netw. 8, 3 (June 2000), 281-293.

[14] Vidanagama, T.N.; Nakazato, H., "Mobility in a description based clustered ad hoc network," GLOBECOM Workshops (GC Wkshps), 2010 IEEE, pp.148-152, 6-10 Dec. 2010.

[15] Deke Guo; Yunhao Liu; XiangYang Li; Panlong Yang, "False Negative Problem of Counting Bloom Filter," Knowledge and Data Engineering, IEEE Transactions on , vol.22, no.5, pp.651,664, May 2010

[16] J. Blustein and A. El-Maazawi, “Bloom filters. a tutorial, analysis, and survey,” Technical Report CS-2002-10.

[17] Bonomi, F., Mitzenmacher, M., Panigrahy, R., Singh, S., & Varghese, G. (2006). An improved construction for counting bloom filters. In Algorithms–ESA 2006 (pp. 684-695). Springer Berlin Heidelberg.

[18] Kun Huang; Jie Zhang; Dafang Zhang; Gaogang Xie; Salamatian, K.; Liu, A.X.; Wei Li, "A Multi-partitioning Approach to Building Fast and Accurate Counting Bloom Filters," (IPDPS), 2013 27th Int. Sym. IEEE,., pp.1159,1170, May 2013.

[19] Rottenstreich, O.; Kanizo, Y.; Keslassy, I., "The Variable-Increment Counting Bloom Filter," IEEE/ACM Trans. on Networking, no.99, pp.1880-88, 2012.

[20] Vidanagama, T.N.; Nakazato, H.; “Message Routing with Bloom Filter for Name-Based Home Ad Hoc Networks”, IEICE Tech. Rep., CS2013-53, pp.75-80, Nov. 2013.

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