Broadcasting Methods in MANETS: An Overview*

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Abstract. Broadcasting in mobile ad hoc networks (MANETs) is an information dissemination process of sending a message from a source node to all other nodes of the network. Even though it has been studied extensively for wired networks, broadcasting in MANETs poses more challenging problems because of the variable and unpredictable characteristics of its medium as well as the fluctuation of the signal strength and propagation with respect to time and environment. Furthermore, node mobility creates a continuously changing communication topology in which routing paths break and new ones form dynamically. In this context, efficient broadcasting in Mobile Ad hoc networks is crucial for providing control and routing information for multicast and point to point communication protocols. This paper presents an overview on the state of the art of broadcasting methods in MANETs and makes recommendations on how to improve the efficiency and performance of tree and cluster based broadcasting methods.

Keywords: MANET, broadcasting, wireless network, binomial tree, performance evaluation, system decomposition.

1 Introduction

A mobile Ad Hoc Network (MANET) is a special type of temporary wireless mobile network of nodes (routers) without the aid of a fixed network infrastructure or centralized administration. It is made up of wireless nodes (routers) that can move around freely and cooperate in relaying packets on the behalf of one another. If a source node is unable to send a message directly to its destination node due to limited transmission range, the source node uses intermediate nodes to forward the message towards the destination node. MANET's applications range from civilian use to emergency rescue sites, such as military battlefields.

The main design and operational challenges of a MANET are reliability, bandwidth and battery power. The network has unpredictable characteristics such as dynamically changing topology, fluctuation of signal strengths with time and

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environment, failures of existing communication routes and on the fly formation of new ones. Thus, communication algorithms and protocols should be very light in computational and storage needs in order to conserve energy and bandwidth (c.f., [1, 2, 3, 4, 5]).

Broadcasting in a MANET is an information dissemination process of sending a message from a source node to all other nodes of the network. This process is important to routing information discovery protocols, which use broadcasting to establish routes such as dynamic source routing (DSR) [6], ad hoc on demand distance vector (AODV) [7], zone routing protocol (ZRP) [2, 8, 9] and location aided routing (LAR) [10].

Broadcasting in MANETs poses more challenges than those in wired networks due to node mobility and scarce system resources. Because of the mobility aspect, there is no single optimal scheme for all scenarios. An important feature characterizing the quality of a MANET is the ability to effectively disseminate the information amongst the nodes of the network. Thus, efficient message dissemination is a key component in achieving high performance in MANETs.

In this context, two main broadcast problems are described below, where a graph $G(U, L)$ is used to represent a MANET with U and L as the set of nodes and links, respectively.

- **One-to-all broadcast problem (broadcasting):** Let us assume that a node u, $u \in U$, knows a piece of information $I(u)$, which is unknown to all other nodes in U. The problem is to find a communication scheme such that all nodes in G learn the piece of information $I(u)$ (c.f., Fig. 1).
- **All-to-all broadcast problem (gossiping):** Given the graph $G(U, L)$ and for all $u \in U$, let $I(u)$ be a piece of information residing in each u. The problem is to find a communication scheme such that each node from U learns the whole cumulative message.

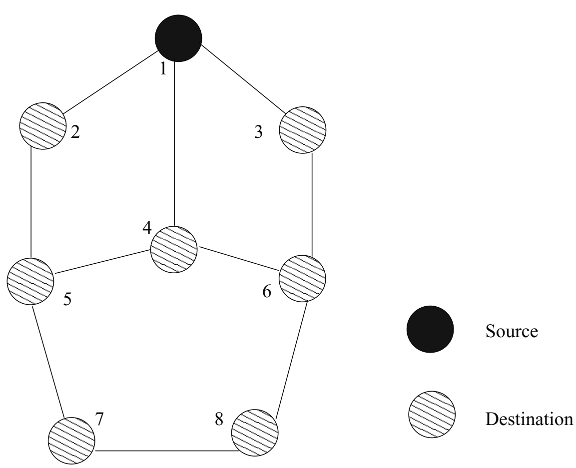

Fig. 1. One-to-All broadcasting

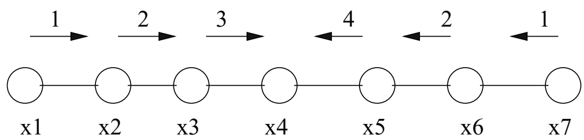

Fig. 2. Half duplex mode

The broadcast problem is to spread the knowledge of one node to all other nodes in the MANET and the gossip problem is to accumulate the knowledge of all nodes in each node of the MANET. Each communication scheme involves a sequence of steps. The term 'communication mode' describes the way how links/nodes may be used or may not be used in one communication step. There are several communication modes investigated in the literature but half and full duplex, single and all port modes have received a lot of interest and are described below.

– **Half duplex:** In this mode and for each single step each node may be active only via one of its adjacent links either as a sender or a receiver. This means that the information flow is one way. Fig. 2 shows an accumulation for the path of 7 nodes and the node $x4$ is depicted. More specifically, in the first step the node x1 sends a message to $x2$ and $x7$ sends a message to $x6$. In the second step, $x2$ sends a message to $x3$ and $x6$ sends a message to $x5$. In the third step $x3$ sends a message to $x4$, and in the fourth step $x5$ sends to $x4$. In these steps one can see that the properties of the half duplex have been satisfied at the last two steps.
– **Full duplex:** In this mode, in a single step, each node may be active only via one of its adjacent links and, if it is active, then it simultaneously sends a message and receives a message through a given, active communication link, i.e., if one link is used for communication, the information flow is bidirectional.
– **Single port:** Each node of the network can access at most one link that is incident to it i.e., only one port can be used at a time. Note that Fig. 2 also satisfies the properties of single port mode.
– **All ports:** Each node of the network can simultaneously access all links incident to it i.e., all ports can be used at a time.

A fast and efficient broadcasting scheme is a fundamental prerequisite underpinning the computational algorithms of MANETs. This is done by a sequence of calls over the links of the MANET, subject to the following two constraints:

– Each communication from one node to another requires a unit time step.
– A node can only communicate with an adjacent node.

For a given graph $G(U, L)$ with m nodes and a node u, $u \in U$, let $b(u, G)$ be the necessary and sufficient number of required steps to solve from node u the

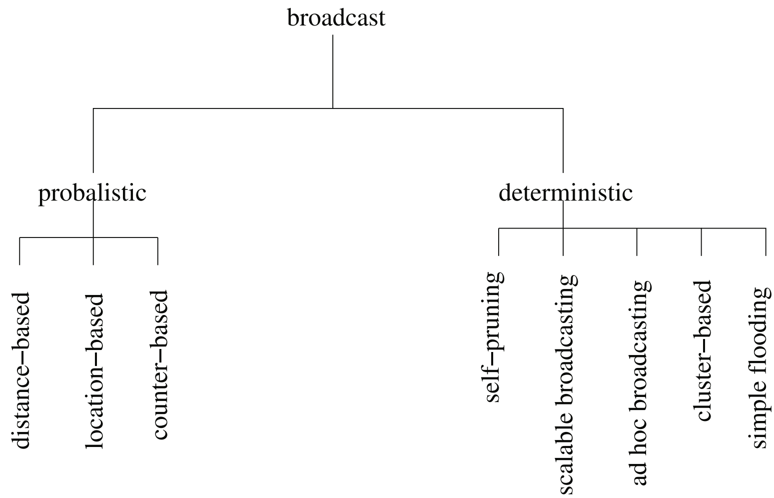

Fig. 3. Broadcasting methods

broadcast problem for graph G in the half duplex communication mode. The broadcast complexity of G in the half duplex mode of communication is defined by $b_{max}(G) = \max\{b(u,G)|u \in U\}$ whilst the lower bound of the broadcast complexity is defined by $b_{min}(G) = \min\{b(u,G)|u \in U\}$ and clearly, the following relation holds: $b(G) \geq \min b(G) \geq \lceil log_2 m \rceil$, where m is the number of nodes in the set U of graph $G(U,L)$. Note that the graphs $G(U,L)$ satisfying the property $b_{min}(G) \geq \lceil log_2 m \rceil$ are called minimal broadcast graphs.

This paper has its roots in a tutorial by Kouvatsos and Mkwawa [11] and provides an overview of some of the main broadcasting techniques in MANETs (c.f., Fig. 3). Moreover, it makes recommendations to improve the efficiency and performance of the current and future broadcasting techniques by using the concept of the binomial tree (c.f., Lo et al [12]) and a decomposition criterion for the design of complex systems (c.f., Kouvatsos [13]).

The paper is organised as follows: Section 2 reviews the probabilistic and deterministic broadcasting methods. Section 3 and 4 review the cluster and tree based broadcasting methods, respectively. The proposed enhancements of cluster and binomial tree-based broadcasting methods are presented in Section 5. Conclusions follow in Section 6.

2 Broadcasting Methods

The broadcasting methods highlighted in this section are based on statistical and geometrical models, which estimate the additional coverage of re-broadcasting. These methods have been categorised into four families utilising the IEEE802.11 MAC specifications [14].

1. The Simple Flooding Method [15, 16] requires each node in a MANET to rebroadcast all packets.

2. The Probability-based Methods [17] assign probabilities to each node to rebroadcast depending on the topology of the network.
3. The Area-based Methods [17] assume a common transmission distance and rebroadcasts a node if there is sufficient coverage area.
4. The Neighbourhood-based Methods [18, 19, 20, 21, 22] maintain the state on the neighbourhood and the information obtained from the neighbouring nodes is used for rebroadcast.

Comparisons amongst these broadcasting methods can be seen in [23, 24]. Apart from Simple Flooding Method, all broadcasting methods aim to optimise energy and bandwidth by minimising message retransmission. Some of these broadcasting methods are described in the following subsections.

2.1 Simple Flooding (SF) Method

According to the SF method, a source node of a MANET disseminates a message to all its neighbouring nodes, each of which will check whether it received this message at an earlier transmission. If yes, the message will be dropped, if no the message will be re-disseminated at once to all their neighbours. The process goes on until all nodes have received the message.

Although this method is very reliable for a MANET with low density nodes and high mobility, nevertheless it is very harmful and unproductive as it causes severe network congestion and a quickly exhaustion of battery power. In a MANET of size m, the number of messages is of the magnitude $\bigcirc(m^2)$ and is depicted in Fig. 4.

2.2 Probability Based Methods

Probability-based (P-B) Approach. The P-B approach tries to solve some of the drawbacks associated with the simple flooding method. Each node $i \in N$ is given a predetermined probability p_i for re-broadcasting. Consequently, as there will be a number of nodes that do not rebroadcast, there will be a related decrease in the degree of the network's congestion and collisions . However, there is a danger that some nodes will not receive the broadcast message. Note that if $\forall i$ such that $p_i = 1$, the probability based approach is reduced to a simple flooding approach. More efficient broadcasting reduces p_i as the number of neighbour density increases and vise versa.

Counter-based (C-B) Scheme. Under the C-B scheme, a random assessment delay (RAD) is set, a threshold K is determined and a counter $k \geq 1$ is formed on the number of times the broadcast message is received. During RAD, the counter k is incremented by one for each redundant message received and if $k > K$ when RAD expires, the message is dropped. Otherwise, it is rebroadcasted. In this approach, some nodes will not rebroadcast in denser MANETs, whilst in a less dense MANETs all nodes will rebroadcast.

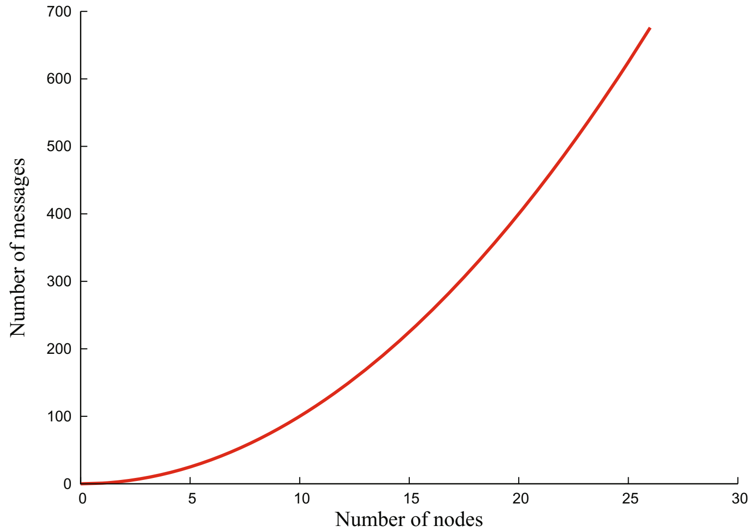

Fig. 4. $\bigcirc(n^2)$ number of messages in a simple flooding method

2.3 Area-Based Methods

Distance-Based (D-B) Approach. The D-B Approach utilises the distance between a receiving node and it's neighbours to decide either to drop a message or to rebroadcast. Let d be the distance between the receiving node and the source node.If d is small, then the rebroadcast coverage of the receiving node is also small. If d is large, then the rebroadcast coverage is large. If $d = 0$, then the rebroadcast coverage is also 0.

A receiving node will normally determine the threshold distance D and set the RAD. Redundant messages will be stored until the RAD expires, in which case all distances from source nodes will be checked and if $d < D$ then the received messages will be dropped, otherwise the messages will be rebroadcast. Ni et al [17] suggested that the signal strengths can be used to calculate the distance from the source node. The role of distance can even be directly replaced by the signal strength by setting the signal strength threshold.

Location-Based (L-B) Approach. According to the L-B approach, each node must have the means to establish it's own location in order to estimate the additional coverage more precisely. This approach can be supported by the global positioning system (GPS) [25]. More specifically, each node in a MANET will add its own location to the header of each message it sends or rebroadcasts. When a node received a message, it will note the location of the sender and compute the additional coverage area to rebroadcast. If this is less than the given threshold, the message is dropped when the RAD expires, otherwise the message will be rebroadcasted.

The problem of the location based approach is the cost of calculating additional coverage areas, which is calculating many intersections among many circles. This will drain the scarcely available energy.

2.4 Neighbour Knowledge Methods

Self Pruning (SP). Each node under SP is required to have knowledge of it's neighbours, which can be achieved by periodic "Hello" messages. The receiving node will first compare its neighbour's lists to the list of the sender node and then it will rebroadcast, if the additional nodes could be reached, otherwise it will drop the message. This is the simplest approach of the neighbour knowledge methods.

As it can be seen in Fig. 5, after receiving a message from node 2, node 1 will rebroadcast the message to node 4 and node 3 as they are its only additional nodes. Note that node 5 also will rebroadcast the same message to node 4 as it is the only additional node. Thus, message redundancy still takes place under SP.

Scalable Broadcasting (SB) Approach. The SB approach improves the SP approach by reducing the number of the chances of message retransmission. Under SB approach, all nodes in a MANET have knowledge of their neighbouring nodes up to a two hop distance. This knowledge is established by "Hello" messages. In this approach, each node has a two hop topology information. In Fig. 5, node 1 receives a message from node 2, since node 2 is a neighbour, node 1 has knowledge of all its own neighbours and also node's 2 neighbours, which have received the broadcast message. The additional nodes of node 2 will receive the message rebroadcast by node 2 with the aid of RAD. Note that still node 4 will receive the redundant message.

Pen and Lu [20] dynamically adjusted RAD according to a given MANET conditions. Each node will look for a neighbour with maximum degree in it's

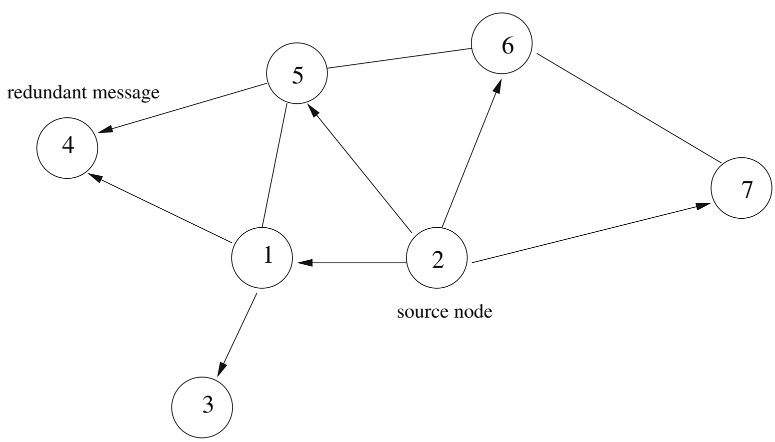

Fig. 5. Self Pruning approach

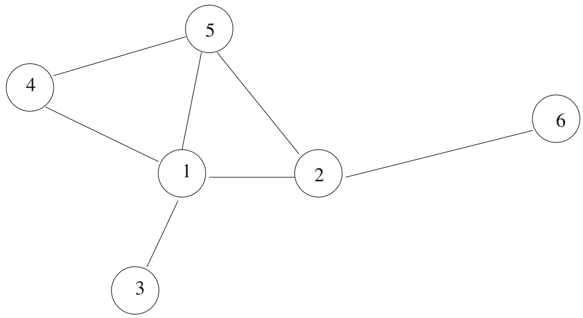

Fig. 6. Ad Hoc broadcasting (AHB) Approach

knowledge base. When a neighbour with the maximum number degree δ_i is found, the RAD is computed based on the ratio $\frac{\delta_i}{\delta}$, where δ is the degree of the current node. Nodes with large RAD will always rebroadcast first.

Ad Hoc Broadcasting (AHB) Approach. According to the AHB approach, only nodes selected as gateway and header nodes are allowed to rebroadcast a message. The AHB approach can be described as follows:-

1. Locate all two hop neighbours that can only be reached by a one hop neighbour and select these nodes as gateways.
2. Calculate the cover set that will receive the message from the current gateway set.
3. Out of the neighbours not yet in the gateway set, select randomly one node that would cover at most two hop neighbours not in the cover set. Set this node as a gateway.
4. Repeat processes 2 and 3 until all two hop neighbours are covered.
5. When a node receives a message and is a gateway, this node determines which of its neighbours already received the message in the same transmission. These neighbours are considered already covered and are dropped from the neighbour used to select the next hop gateways.

In Fig. 6, node 2 has 1, 5 and 6 nodes as one hop neighbours, 3 and 4 nodes has two hop neighbours. Node 3 can be reached through node 1 as a one hop neighbour of node 2. Node 4 can be reached through node 1 or node 5 as one hop neighbours of node 2. Node 2 selects node 1 as a gateway to rebroadcast the message to nodes 3 and 4. Upon receiving the message node 5 will not rebroadcast the message as it is not a gateway.

2.5 Shortcomings of Existing Broadcasting Methods

The shortcomings of the aforementioned broadcasting methods for MANETs are deduced below from a detailed comparative study carried out by Williams and Camp [23].

1. All methods apart from the Neighbour Knowledge Methods, require more rebroadcasts, with respect to the number of retransmitting nodes [17].
2. Methods making use of RAD, such as the Probability-based C-B scheme and the Area-based D-B and L-B methods, underperform in high density MANETs unless a mechanism to dynamically adjust RAD to its network conditions is developed.
3. The AHB approach runs into difficulties in a very high mobile MANET due to not making any use of local information to decide whether to rebroadcast or not.

Based on the comparative studies in [23], none of the existing broadcasting protocols are satisfactory for wide ranging MANET environments. Because of its adaptive nature, the SB approach has significant improvements over the non adaptive approaches.

Due to these shortcomings there is a need to develop new efficient broadcasting approaches with the common goal of conserving the available scarce resource in MANETs.

3 Cluster-Based Methods

In this section clustering based methods, which are founded on graphic theoretic concepts are reviewed. Note that the clustering approach has been used to address traffic coordination schemes [26], routing problems [26] and fault tolerance issues [27]. Note that the cluster approach proposed in Ni et al [17] was adopted by Jiang et al [28] in order to reduce the complexity of the storm broadcasting problem.

Each node in a MANET periodically sends "Hello" messages to advertise its presence. Each node has a unique identification (ID). A cluster is a set of nodes formed as follows: A node with a local minimal ID will elect itself as a cluster head. All surrounding nodes of a head are members of the cluster identified by the heads ID. Within a cluster, a member that can communicate with a node in another cluster is a gateway. To take mobility into account, when two heads meet, the one with a larger ID gives up its head role. This cluster formation is depicted in Fig. 7.

More specifically, Ni et al [17] assumed that the cluster formed in a MANET will be maintained regularly by the underlying cluster formation algorithm. In a cluster, the heads' rebroadcast can cover all other nodes in it's cluster. To rebroadcast message to nodes in other clusters, gateway nodes are used, hence there is no need for a non-gateway nodes to rebroadcast the message. As different clusters may still have many gateway nodes, these gateways will still use any of the broadcasting approaches described in Section 2 to determine whether to rebroadcast or not. In particular Ni et al [17] showed that the performance of the L-B cluster-based method compared favourably to the original location based scheme. The method saved a lot more rebroadcasts and lead to shorter average broadcast latencies. For low density MANETs , however, its reachability was poor.

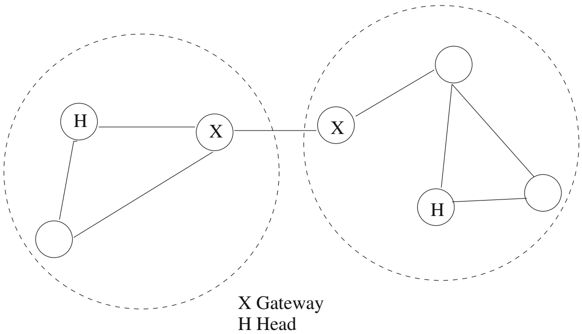

Fig. 7. Clustered MANET

4 Tree-Based Methods

Although broadcasting using tree methods in wired networks is a well known and widely used technique, it is typically claimed to be inappropriate for MANETs because of their dynamic change in network topologies. To the contrary, Juttner and Magi [29] have shown that a tree based method is an efficient, reliable and stable even in case of the ever changing network structure of the MANETs.

The tree constructed in [29] was a spanning tree (i.e., a spanning tree of $G(U,L)$ is a selection of links of $G(U,L)$ that form a tree spanning every node of $G(U,L)$). The broadcasting using this tree was achieved by forwarding a broadcast message not to all neighbours but only to those who are neighbours of this tree. Since a tree is acyclic, each message is received only once by each node, giving advantages over the existing methods.

Several proposed algorithms in the literature may be used for constructing and maintaining trees such as the spanning tree algorithm of bridged Ethernet networks [30]. However, most of these algorithms are developed to work for stable networks and not in the constantly changing topology of a MANET. The authors in [31, 32, 33, 34, 35] focused their work into the study of generic multicast trees, whilst Perkins et al [36] dealt the analysis of multicast trees in MANETs. These algorithms, however, are not suitable for handling the ever changing topologies of MANETs. Other algorithms although involve the construction of a spanning tree, they are not appropriate for the maintenance of the tree in a dynamically changing topology [29].

A feature that differentiates the tree based method reported in Juttner and Magi [29] from the other methods is that it specifically optimises the concept of one-to-one transmissions. In this way the many drawbacks of local broadcasts do not affect the algorithm and thus, the method is very well suited to perform reliable broadcasts. Moreover, whilst all other methods require extra messaging to keep up network states, the proposed method in [29] has been designed to minimise this extra signalling traffic. More details on how the algorithm constructs and maintains the spanning tree can be seen in [29].

5 Enhancements of the Cluster and Tree-Based Methods

5.1 A Cluster-Decomposition-Based Method

Some of the shortcomings in the existing cluster-based broadcasting methods in MANETs (c.f., Section 3) can be addressed by adopting an information theoretic decomposition criterion proposed by Kouvatsos (c.f., [13]) for the hierarchical design of a complex system, S. In this context, system S was represented by a graph $G(U,L)$, where U is the set of m nodes and L is the set of links.

The decomposition criterion aims to decompose system S (or, graph $G(U,L)$) into most independent subsystems $\{S_1,S_2,\ldots,S_\mu\}$ (or subgraphs $G_1,G_2,\ldots,G_\mu$) and thus, minimise the information transfer amongst them (c.f., [13]). It is based on *i*) a multivariate binary probability measure, constructed on a succession of multiple linear regression models *ii*) the information theoretic concept of entropy function (c.f., Shannon [37]) and *iii*) the Gibbs Theorem (c.f., Watanabe [38]), leading into the minimization of the information transfer amongst $\mu(1<\mu\leq m)$ subgraphs $G_1,G_2,\ldots,G_\mu$ of a graph $G(U,L)$ representing subsystems $\{S_1,S_2,\ldots,S_\mu\}$, respectively. The theoretical and practical results in [13] revealed that the logical structure of a complex system, S, represented as a graph $G(U,L)$, may be expressed in the form of a hierarchical tree-like structure (c.f., [39]).

Each partition π belongs in a specific partition-type $\Pi=\{\pi_1,\pi_2,\ldots,\pi_\mu\}$, which is the set of all partitions $\{\pi_i, i=1,2,\ldots,\mu, 1<\mu\leq m\}$, each of which imposes, respectively, the same cardinality in each subsystem in a subset $\{S_1,S_2,\ldots,S_\mu\}$. The optimum partition can be determined by employing the aforementioned decomposition criterion, which is expressed by $\min_{\pi}\left\{\sum_{\pi\in\Pi}\rho_{ij}^2\right\}$, where ρ_{ij}, $(|\rho_{ij}|\leq 1)$ is the correlation coefficient of binary random variables $\{z_i,z_j,i\neq j,i,j=1,2\ldots,m\}$ associated with each pair of nodes (i,j) of graph $G(U,L)$. Note that each $z_i, i=1,2,\ldots,m$ cuts the domain of all different design solutions (i.e, forms) for the system S into two sets such that z_i takes the value 0 with probability p_i, for the set of forms that the node i fits and the value 1 with probability $q_i=1-p_i$ for the set of forms that it doesn't fit (c.f., Alexander [39]). Moreover, $\sum_{\pi\in\Pi}\rho_{ij}^2$ is the sum of ρ_{ij}^2 of the links $\{u_i\rightarrow u_j\}$ cut by the partition π, $\pi\in\Pi$, whilst $\sum_{\pi\in\Pi}\rho_{ij}^2$ expresses the degree of interconnection amongst the subsystems.

In the context of MANETs, the decomposition criterion can be interpreted by analogy as the $\min_{\pi}\left\{\sum_{\pi\in\Pi}\omega_{ij}^2\right\}$, where $\sum_{\pi\in\Pi}\omega_{ij}^2$ is the sum of the squares of average aggregate signal strengths on the links $\{u_i\rightarrow u_j\}$ of set L cut by the partition. Each partition type Π offers a number of possible decompositions of graph $G(U,L)$. Within each partition type Π, that partition π with the smallest $\sum_{\pi\in\Pi}\omega_{ij}^2$ is chosen. However, it is not feasible to identify the optimum $\sum_{\pi\in\Pi}\omega_{ij}^2$ amongst the available partition types which cut different number of links according to the cardinality of $G_1,G_2,\ldots,G_\mu$ and the topology of graph $G(U,L)$. Hence, the optimum partition π over all partition types can be determined by

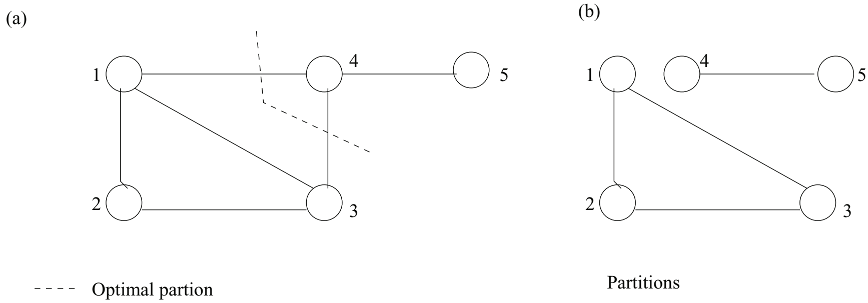

Fig. 8. Decomposition of graph G into most independent subgraphs

applying a normalisation on $\sum_{\pi \in \Pi} \omega_{ij}^2$ namely $N(\pi) = \frac{\min_{\pi} \sum_{\pi \in \Pi} \omega_{ij}^2 - E(\sum_{\pi \in \Pi} \omega_{ij}^2)}{(var(\sum_{\pi \in \Pi} \omega_{ij}^2))^{\frac{1}{2}}}$, where $E(\sum_{\pi \in \Pi} \omega_{ij}^2)$ and $var(\sum_{\pi \in \Pi} \omega_{ij}^2)$ are the mean and variance of $\sum_{\pi \in \Pi} \omega_{ij}^2$ respectively (c.f., [39, 40]). An illustration of the decomposition of a graph with five vertices is displayed in Fig. 8.

The normalisation procedure leads to the optimal decomposition of a MANET viewed as a system S into subsystems $\{S_1, S_2, \ldots, S_\mu\}$ whilst repeated applications of the decomposition process for each subsystem $\{S_i, i = 1, 2, \ldots, \mu\}$ will identify a tree structure with one root and m leaves. The root component represents the MANET as an entire design problem, the leaves are the individual nodes and the intermediate components (i.e., subsystems) are the subsets of nodes representing the most independent design subproblems. Thus, using the normalisation process to implement the decomposition criterion, the logical structure of the MANET has a tree-like representation, which can be constructed in a top-down manner. In this sense, the strongest interactions between the nodes of the MANET (i.e., system's design requirements) are satisfied at an early stage in the procedure before any irreversible decisions have been taken, and moreover, any system failure can be rectified within a subsystem (or, module) causing the least possible disturbance to the rest of the system.

The decomposition of the MANET's nodes into clusters of strongly (in terms of signal strengths) connected nodes will solve the problem of reachability of nodes within clusters and between gateway and head nodes with their respective cluster nodes. The proposed graph decomposition-based method can be employed to enhance the existing cluster-based schemes described in Section 3.

5.2 A Binomial Tree-Based Method

In the context of one-to-one transmission mechanism (c.f., [29]), a spanning tree will not give an optimal time. Therefore, it seems appropriate to design and develop efficient broadcasting schemes that aim to enhance the tree based methods (c.f., Section 4) and improve the broadcasting time in MANETs. In this section, the concept of a binomial tree is suggested for this purpose.

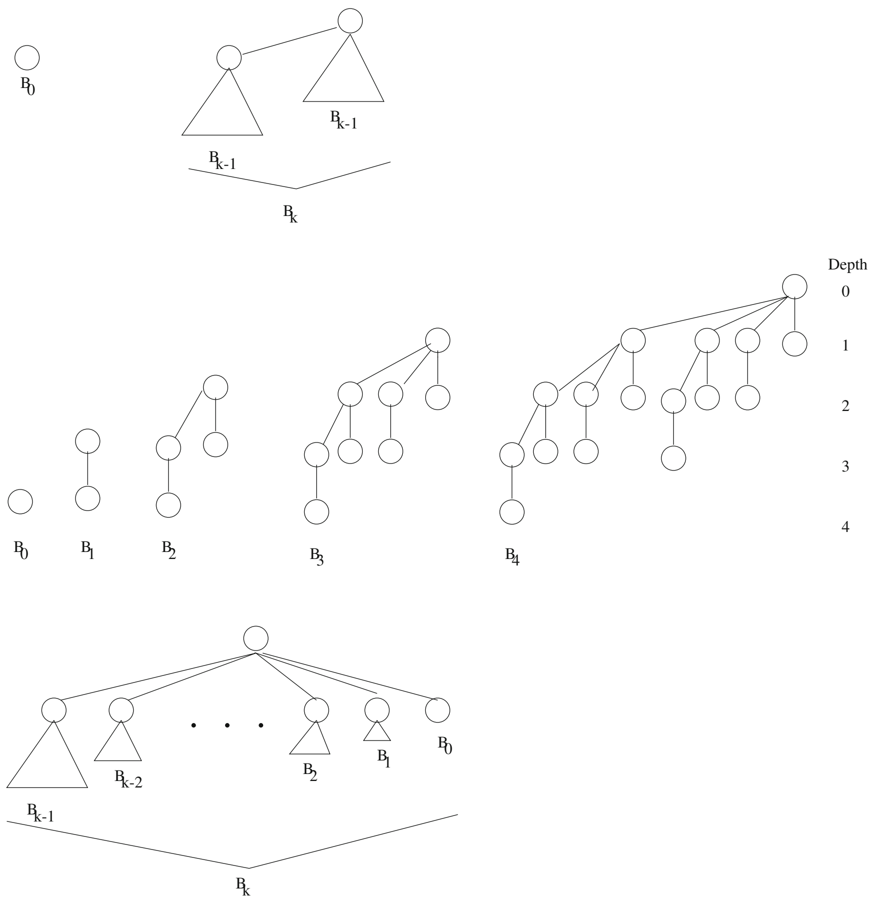

Fig. 9. A binomial tree B_k

A binomial tree structure is one of the most frequently used tree structures for parallel applications in various systems. Lo et al [12] has identified the binomial tree as an ideal computation structure for parallel divide and conquer algorithms. Binomial trees can easily be embedded into a fully connected graph with constant dilation 1 (c.f., [41]). In an one-to-one transmission, the binomial tree at each step at most doubles the informed number of nodes and thus, it gives an optimal broadcasting time.

A binomial tree B_k is an ordered tree defined recursively (c.f., Fig. 9). For the binomial tree B_k, there are $n = 2^k$ nodes, the height of the tree is k and the root has degree k. The maximum degree of any node in a binomial tree is $log_2 n$ and all nodes are labelled as binary string of length k.

For a binomial tree, there are exactly $\binom{n}{i}$ nodes at depth i for $i = 0, 1, \ldots, k$, and the root has degree k, which is greater than that of any other node. Moreover, two nodes are connected if their corresponding strings differ precisely in one position. The root node (i.e., a node at depth $i = 0$) of the tree is labelled as

$000\ldots0$ where k binomial trees are attached. Nodes at depth $i = 1$ will have a single 1 in their labels in ascending order from left to right (i.e., $u_1 < u_2 < u_3 < \ldots u_{\binom{n}{i}}$). Nodes at depth $i = 2$ will have a two 1s in their labels in ascending order from left to right. This goes on to the last node of the tree at depth k with $111\ldots1$ as a label.

In the context of a one hop ad hoc network, the binomial tree will reduce the number of forwarding nodes into at most $\frac{N_1(u)}{2} - 1$ as there $\frac{N_1(u)}{2}$ leaf nodes.

The binomial tree can easily reconfigure as nodes leave and join the transmission range. A node joining the transmission range will be connected to depth 1 of the tree provided that $|i| < \binom{n}{i}$, where $i = 1$ and $|i|$ represents the number of nodes at depth i. If $|i| = \binom{n}{i}$ for $i = 1$, then the joining node will start a new level 0.

If any node at any depth i, $0 \leq i \leq k$ leaves the transmission range, the far right node of depth 1 (i.e., u_j, $1 \leq j \leq \binom{n}{i}$) will take the position of the leaving node. No action will be taken if the far right node of depth 1 leaves the transmission range.

For a multi hop MANET, the tree structure will be a heap of binomial trees. The MANET will look like a cluster of binomial trees. A heap of binomial trees is a grouping of binomial trees that has the following binomial heap properties:-

1. No two binomial trees in the group have the same size.
2. Each node of each tree has a unique key.
3. Each binomial tree in the group is heap ordered, i.e.,, each node except a root node to have a key less than the key of its parent.

Each node keeps in a heap of binomial trees the info fields:-

1. Its own field key.
2. Its own field degree.
3. Child pointer field, this points to its left most child.
4. Sibling pointer field, this points to the right most sibling.
5. Parent pointer field, this points to the parent node.

For broadcasting in a MANET, the following operations with their corresponding worst case time complexities (represented by big $\bigcirc$ notation which establishes an upper bound on time complexity and big Θ notation which describes the case where the upper and lower bounds are on the same order of magnitude) are expected in a heap of binomial trees:-

1. Creating of a new heap, $\{\Theta(1)\}$.
2. Searching for the minimum key, $\{\Theta(log_2 n)\}$.
3. Joining two binomial heaps, $\{\bigcirc(log_2 n)\}$.
4. Inserting of a node, $\{\bigcirc(log_2 n)\}$.
5. Decreasing a key, $\{\Theta(log_2 n)\}$.
6. Removal of a node, $\{\Theta(log_2 n)\}$.

The proofs of the above time complexities can be found in Ralf [42];

6 Conclusions

Broadcasting is one of the most essential operations of MANETs and, thus, it is imperative to utilize the most efficient broadcast methods possible as well as design and develop novel ones in order to ensure high network reliability and performance.

This tutorial paper was based on the overview of some major broadcasting methods for MANETs suggested in the literature focusing on their functionalities and shortcomings. Moreover, the adoption of a graph theoretic decomposition criterion and the concept of the binomial tree were suggested in order to enhance, respectively, the efficiency and robustness of the cluster and tree based methods. These broadcasting methods may be adopted in the context of the decentralised optimal control of Robotic mobile wireless Ad hoc NETworks (RANETs), leading into performance enhancement (c.f., [43]), robustness to local failures, scalability and a wide range of applications (e.g., [44]).

Due to the dynamic changes of MANET's topology and its scarce resource availability, however, there is no at present single optimal algorithm that could be applicable to all relevant scenarios. Towards this goal, further analytic investigations are recommended into the proposed enhancements of the cluster and tree based broadcasting methods for MANETs in conjunction with related experimental performance evaluation studies.

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