International Journal of Scientific Engineering and Applied Science (IJSEAS) - Volume-1, Issue-8,November 2015
ISSN: 2395-3470
www.ijseas.com

Time sequence based approach to achieve optimal broadcast in wireless networks

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Abstract—Wireless network node uses broadcasting technique for data transmission. There exist many protocols like simple routing, table driven routing protocol, on demand routing protocol for transmission and each method has its own conflicts. Here we are presenting a new approach by using dynamic topologies with online local broadcasting algorithm called time sequence scheme. This Time Sequence Scheme algorithm ranks the transmission from broadcasting node so it reduces number of rebroadcasts in a network. The performance of TSS algorithm comes close to many theoretically best algorithms even with the presence of collision and high mobility. We also demonstrate that the performance of TSS is robust in context of mobility included topology reconfiguration during broadcast of messages.

Key words—Wireless communication, distributed broadcast, efficient flooding, connected dominated set

1. Introduction

In any wireless networks broadcasting is the fundamental operation, in which a source node sends messages to all other nodes in the network. The node in a wireless network are limited in energy and computational power, hence we require an efficient broadcast mechanism. Also we need a robust broadcast technique for networks using dynamic reconfigurable topologies. On demand routing protocol proposed earlier will discover a new route only when there is traffic to be routed. AODV, DSR, ZRP are examples of such protocols. These protocols are also called as reactive routing protocols.

Since data dissemination to all nodes in network is mandatory, broadcasting is the obvious solution. But it is to note that the broadcast technique should support the limited energy capability of network nodes. The main objective of this paper is to use an efficient broadcasting algorithm called Time Sequence Scheme (TSS) along with dynamic topologies. This TSS algorithm orders the node transmission in time. Hence it reduces number of rebroadcast in a network. Also TSS utilizes one-hop topology information yet covers the entire network with low latency.

This efficient broadcast technique also aims for the use of dynamic topologies. TSS retains its performance in full network stack implementation, even with the packet loss at MAC layer, for instance. We also compare the proposed technique with the most efficient scheme till date in the technical literature, and it outperforms all.

In summary, the algorithm proposed is efficient, distributed, performs well in highly dynamic network and relies on local coverage information.

2. Efficient Broadcasting

2.1 Connected dominated set

Considering a network as a connected graph G=(S,E), where S is set of all network nodes and E is set of all links. Taking source node as S_0 and $S_0 \in S$ transmits message m and it is desirable to reduce the number of rebroadcasts of m which is required to propagate m in the entire network. Consider the set of nodes $Q \subseteq S$, if Q is a connected sub graph of G, Q forms a connected dominating set (CDS). Note that after the termination of any broadcast scheme that propagates m to all nodes in S, the set of nodes that the scheme has picked for broadcast forms a CDS.

A Minimum Connected Dominating Set (MCDS) of G is a CDS in G with minimum cardinality. If just all the nodes in a MCDS broadcast message m, all nodes in G will receive m and the number of broadcast nodes is minimized. In the context of wireless networks, we observe that minimizing the number of rebroadcasts would expend substantially less energy and band-width especially as compared to flooding. Also the recent practical variants of flooding, such as Glossy and Flash can be very rapid and m reaches all nodes with remarkably low latency sans finding MCDS. However, in many cases the design and application of these flooding schemes is orthogonal to the task of finding MCDS. I.e., the number of transmissions can be minimized by, first, finding the set, Q, of network nodes forming a MCDS; and, second, constraining the flooding only within Q one can minimize latency. Such approach was shown to significantly reduce the energy cost of the Flash flooding protocol.

The minimum connected dominating set can be given as,

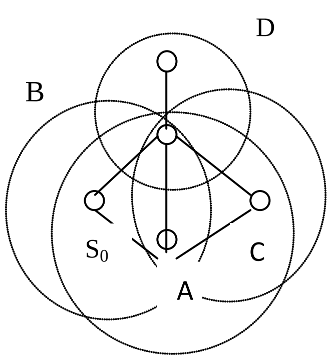

Fig.1 connected dominating set (CDS)

Where, S_0 is the source node. All other nodes are connected together forming a connected set. Here the connected set transmits message to all the nodes in network.

2.2 Desired features for dynamic reconfigurable wireless networks

The algorithm proposed,

(1) Covers all the network nodes,
(2) Transmits the broadcast message as few times as possible (or, equivalently, reduce the number of times that the broadcast message is received by a network node)
(3) Minimizes delay (i.e., the time for the message to be received by entire network)
(4) Requires only locally available information (e.g., only knowledge of the 1-hop neighborhood topology).

Any broadcasting mechanism should satisfy these requirements for efficient transmission. The existing method uses pure flooding approach which ends up in broadcast storm problem. Also they provide poor network coverage and performance degradation in dynamic topologies. This proposed technique satisfies these requirements and reduces the latency.

3. System model

The network model consists of N equal capability nodes with unique IDs, randomly distributed in a 2D plane. However, the results in this paper can be applied to 1D and to 3D networks. The transmission range of all nodes is r [meters]. Two nodes are referred to as 1 hop neighbors (or simply as neighbors) and can communicate directly if the Euclidean distance between them is less than R [meters]. Thus, the network is modeled as a Unit Disk Graph (UDG).

On the MAC layer, we consider two scenarios: a) a perfect MAC layer to isolate other effects (e.g., collisions, links asymmetry, etc.), so that the broadcast performance metrics reflect only the algorithmic efficiency; and b) packet loss (at the MAC and other network layers) to evaluate the performance of the algorithm in practical network settings, where collisions and links asymmetries, among other deleterious effects, are present. The system operation is time slotted, and the network nodes are assumed to be only coarse grain synchronized.

Regarding this algorithm, we have to know certain definitions before getting into it.

Definition 1: A broadcast session is the operation of delivering a message m, created at source to all the other network nodes.

Definition 2: A covered node is a node that has already received the broadcast message in a prior transmission of the broadcast session. To simplify notation, in what follows we assume only a single message m needs to be propagated in the network, during the duration of each broadcast session.

The source node of a broadcast session is always covered. A node that has not received the broadcast message at a particular time, t, is referred to as an uncovered node at t.

Definition 3: The “residual coverage (RC)” of a covered node s ($s \in S$) at a particular time t, referred to as RC (s), equals the number of its 1-hop uncovered neighbors at time t.

Definition 4: We define C as the set of all covered nodes at a particular time and Q as the set of nodes that have already transmitted the message at a particular time. We further define NE(s) as the set of all the neighbors of the node s ($s \in S$).

Finally, we assume all nodes are cooperative.

4. Structure and function of algorithm

4.1 TSS process

The basic idea of the algorithm finding the MCDS is to repeatedly select nodes for transmission, such that in each round a node whose transmission covers the largest number of uncovered nodes is selected. Thus, each transmission removes the largest possible number of nodes from the set of uncovered nodes and, eventually, results in covering the whole network with a minimized number of transmissions.

The following distributed Time Sequence Scheme (TSS) approximates the centralized greedy transmissions order in time, by allowing nodes with larger RC values to transmit before nodes with smaller RC values.

TSS's blueprint is given as follows:

- Upon network deployment each node runs Algorithm 1. Algorithm 1 generates sequence T of time-slots spanning the duration of the broadcast session.

- Source s_0 transmits message m and covers its neighbors.

- Each node i receiving m for the first time mark itself as covered and computes RC (i). The local RC computation by nodes is discussed later in the paper.

- Next, node i runs Algorithm 2 to schedule itself for later transmission time-slot T_b depending on RC (i).

- If node i is scheduled to transmit in some time-slot T_b, i computes RC (i) in the beginning of T_b. If the residual coverage of i has decreased (but is still positive) since the time-slot in which i has scheduled itself, i re-runs Algorithm 2 and schedules itself for a new, later transmission time-slot. Else, still in T_b and prior to broadcast, i checks whether any of its 1-hop neighbors are scheduled to transmit within T_b as well. If more than one neighboring nodes are scheduled for T_b, the node with the largest RC transmits in T_b. The rest of the neighboring nodes schedule themselves to transmit in the next time-slot.

Next, we describe the details of the time sequence T's structure as generated by Algorithm 1. We also discuss the scheduling Algorithm 2, and how it exploits the structure of T to rank, prioritize and order nodes transmissions in time.

4.2 Time sequence structure

Let T be a sequence of time slots and assume $\tau_x < \tau_{x+k}$, $0 < k \leq |T| - x$. Namely, each subsequent time slot is associated with a strictly lower threshold value of RC than the previous time slot's threshold. Upon receiving a broadcast message, node i marks itself as covered, determines RC (i), and schedules itself to transmit in a future time slot T_b . Since i can only schedule itself for a time slot T_b such that $\tau_b \leq$ RC (i), the higher RC (i) the earlier the scheduled T_b. That is, nodes with higher RC would tend to broadcast earlier than nodes with lower RC. This simple scheme does not take into account the fact that as scheduled nodes transmit, for instance in time-slot T_b , the set of newly covered nodes may contain nodes with RC values larger than τ_b. In other words, the time slots following T_b cannot be used to time order the transmissions of such newly covered nodes, since these node’s RC values are greater than the thresholds of all time slots following T_b.

To address this problem, we modify the time

International Journal of Scientific Engineering and Applied Science (IJSEAS) - Volume-1, Issue-8,November 2015
ISSN: 2395-3470
www.ijseas.com

sequence T utilizing Algorithm 1, so that T contains repeated reordering of time slots within epochs (also referred to as levels). Each epoch now contains a sequence of timeslots, and each subsequent timeslot within an epoch has RC threshold strictly lower than the previous timeslot's threshold. However, at the beginning of each epoch, the RC threshold is reset, the first timeslot in each epoch has RC threshold equal to the RC threshold τ_1 of the first timeslot in T..

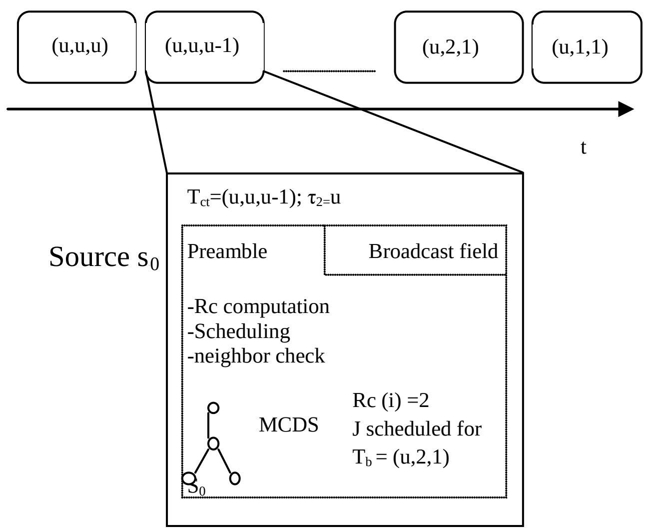

Fig.2 Time sequence t with output of the algorithm

4.3 Node Scheduling and Algorithm 2

Given the time sequence (TS) structure described above, each node locally schedules its time of transmission, after receiving broadcast message m so that, overall, nodes with higher RC transmit earlier than nodes with lower RC. The TS serves as a common reference for all nodes.

The broadcast session begins when source node s_0 broad-casts message m. As m propagates throughout the network, any node j upon receiving m for the first time determines the current time-slot T_{ct} within the TS.

The TS schemes temporal flow proceeds as node j determines its residual coverage RC (j). After determining RC (j), node j runs Algorithm 2 to schedule its transmission for a future timeslot. Given T_{ct} and RC (j), Algorithm 2 schedules node j for a transmission timeslot, T_b, later in the broadcast session. T_b could be the next timeslot immediately after T_{ct} provided RC (j) is large enough (i.e., RC (j) > $middle_{ct}$). Otherwise, Algorithm 2 attempts to schedule node j for a time-slot at the current level, if RC (j) ≥ $lower_{ct}$. If the current time-slot is an edge slot algorithm 2 attempts the next level of the time sequence. Else, node j is scheduled to transmit at a later, lower level. In general, the larger RC (j), the earlier is the level and the earlier is the scheduled transmission timeslot T_b within that level. If RC (j) = 0 the node is not scheduled for transmission at all.

It is important to note that the value of RC (j) can change between the times at which j had scheduled itself for transmission and the beginning of j's scheduled for transmission timeslot T_b, due to transmissions of other nodes or due to mobility. This may render j inadmissible in T_b. To avoid transmission in an incorrect timeslot, j re computes its RC value prior transmitting in T_b and checks if it still can transmit in T_b. If so, j transmits the message in T_b. Else, it reschedules itself by employing Algorithm 2 again with inputs T_{ct} = T_b and the latest recomputed RC (j).

5. Output of the algorithm

5.1 Performance evaluation

We performance of the algorithm is, defined by a number of metrics, of various broadcast algorithms in four distinct network topology models. For a static network topology, we consider the case of a perfect MAC-layer (no packet loss due to collisions). Next, we implemented NTSS and TSS in full network stack, where packets may be lost at different network layers (e.g. due to collisions, noise etc.) Finally, we consider two types of realistic mobile models: one generating independent mobility patterns of the nodes, and another generating correlated group mobility patterns.

We compared the performance of the TS-based schemes against the most efficient schemes found in the technical literature to the best of our knowledge. In particular, we simulated the RBS the authors show that RBS outperforms a few well known broadcast algorithms such as the edge forwarding algorithm. Another broadcast protocol we implement for comparison in this paper is

Border cast: the route discovery mechanism in the Zone Routing Protocol (ZRP). Border cast relies only on local topological information to select the nodes, which forward the broadcast message. Per ZRP a zone of node A in the net-work includes all nodes that are within k hops from A. Border nodes are those nodes in the zone whose minimum hop distance from A is exactly k. According to the Border cast algorithm, the goal is to cover most efficiently only all of the border nodes in its zone.

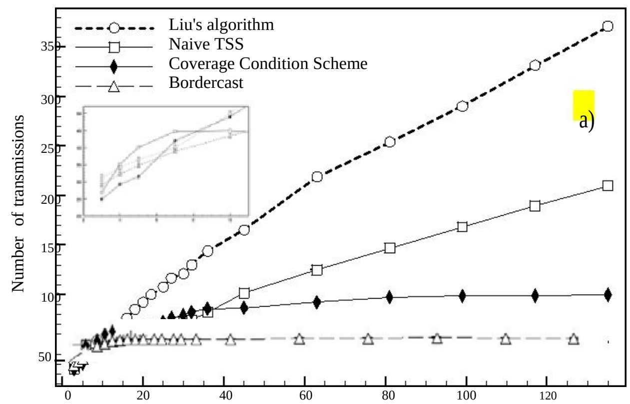

Fig.3 Average node degree

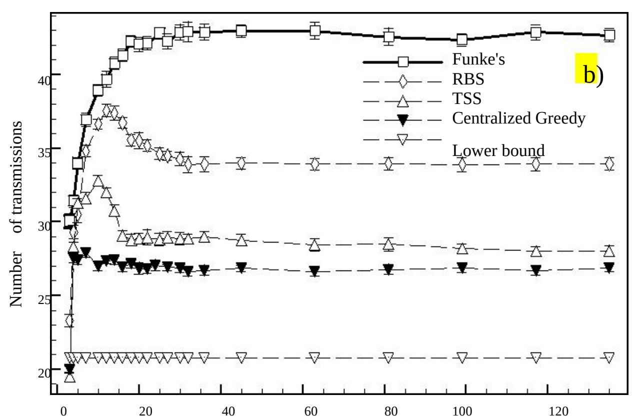

Fig.4 Average node degree

To include an algorithm that constructs a backbone structure prior to the broadcast session, we selected Funke's algorithm as it arguably provides one of the theoretically closest constant approximation ratio to MCDS: 6.94. Finally, for comparison, we also simulated Liu's algorithm a node forwarding algorithm that relies on 1-Hop positional information.

In all the experiments, unless otherwise indicated, the simulation area is a 200[m] x 200[m] square; the inner square area is of dimensions (200 - r)[m] x (200 - r)[m] to avoid edge effects. r [m] is the transmission radius of all nodes and is set to r = 25[m]. The number of nodes in the network varies from 200 up to 3000 nodes to investigate the schemes' performance at different node densities.

5.2 Dynamic Network Topology

In addition to TSS, we evaluated two state-of-the-art online, dynamic broadcast schemes. Using Gaussian-Markov Mobility Model (GMMM) each node follows independent realistic trajectory of movement. Under the Self-Similar Least Action Model (SLAW) model subsets of the network nodes follow correlated paths.

Individual Movement: Gauss-Markov Mobility Model per GMMM, time is split into time intervals (independent of the TS-based schemes time-slots). At the beginning of the k^{th} time interval, nodes velocity is updated according to the following rule: $v[k] = \alpha v[k-1] + (1-\alpha)\bar{v} + (1-\alpha^2)^{0.5} z[k-1]$ Here, $v[k-1]$ is the velocity (speed and direction) of a node in the $[k-1]^{th}$, time interval; $z[k-1]$ is the observation of a Gaussian random variable at time interval $[k-1]$; $\bar{v}$ is the mean value of the velocity; and α is a parameter that determines the degree to which the current velocity at step k depends on the velocity at time interval $[k-1]$. As α approach 1, nodes motion becomes more constant; as α approaches 0 nodes' motion becomes more random.

The number of transmissions and the corresponding achieved network coverage by the four algorithms at different average speeds. The TSS performance is robust since each node checks its residual coverage at least twice (at the time a broadcast message is received and prior to transmission in the scheduled-for-transmission time-slot). Note also that TSS is partially resilient against temporal disconnections of nodes from the network due to mobility.

More specifically, suppose in the Preamble of timeslot T_{ct}, j has a relatively smaller number of neighbors compared to the average node degree in the network. Then, node j is scheduled for a broadcast time-slot T_b that is late in the TS. This gives j more time to potentially move in areas with higher number of neighbors and increase RC (j). Meanwhile j becomes disconnected from the network at some timeslot between T_{ct} and T_b.

6. Conclusion

In this paper, we introduced a combination of TSS algorithm and efficient dynamic topologies, for broadcasting in wireless networks based on finding a distributed approximation of the wireless network MCDS. Through simulation is based on two metrics the transmission complexity and the delay were less than the leading broadcasting schemes. The TSS scheme outperforms all other schemes with respect to the number of broadcast message transmissions, without requiring additional equipment, such as GPS. Furthermore, this performance is achieved with bounded latency, and is independent of network density. Next, we considered the performance of TSS in mobile networks. We showed that TSS possesses network partitioning immunity and outperforms the other schemes with respect to network coverage in all mobility models simulated, achieving almost full coverage. This feature makes TSS one of the few broadcast alternatives to flooding in the context of mobile networks.

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A	**2** / (4,2,2)
B	**3** / (4,3,3)
C	**1** / (4,1,1)
D	**1** / (4,1,1)

Scheduled Nodes	*RC/Scheduled Timeslot*
A	*2 / (4,2,2)*
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