Impact of Mobility Constraints on Epidemic Broadcast in DTNs

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In this paper, we investigate the effect of mobility constraints on epidemic broadcast mechanisms in DTNs (Delay-Tolerant Networks). Major factors affecting epidemic broadcast performances are its forwarding algorithm and node mobility. The impact of forwarding algorithm and node mobility on epidemic broadcast mechanisms has been actively studied in the literature, but those studies use generally unconstrained mobility models. The objective of this paper is therefore to quantitatively investigate the effect of mobility constraints on epidemic broadcast mechanisms. We evaluate the performances of P-BCAST (PUSH-based BroadCast), SA-BCAST (Self-Adaptive BroadCast), and HP-BCAST (History-based P-BCAST) with a random waypoint mobility model with mobility constraints.

1 Introduction

An epidemic broadcast is a store-and-carry message forwarding for one-to-all communication [1]. In an epidemic broadcast, all nodes perform the same probabilistic message forwarding, and a message is repeatedly forwarded among encounter nodes. Every node generally has very limited knowledge on the network (e.g., existence of neighbor nodes). Hence, an epidemic broadcast is a sort of decentralized autonomous mechanisms; i.e., no centralized controller exists for performing broadcast communication.

Major factors affecting epidemic broadcast performances are its forwarding algorithm (e.g., the forwarding probability, the number of copies, usage of the message history, and usage of knowledge exchange among nodes) and node mobility (e.g., velocity, destination, path selection of nodes, and interference with other nodes) [2]. The impact of forwarding algorithm and node mobility on epidemic broadcast mechanisms has been actively studied in the literature (see, for example, [1, 3, 4]), but those studies use unconstrained mobility models such as random walk [2], random waypoint [2], aggregation point [1], and swarm mobility [1]. Hence, the impact of mobility constraints on epidemic broadcasts has not been well understood.

However, in reality, mobility of a node is usually restricted by several mobility constraints such as path constraints, with which a node has to move along one of predetermined paths (e.g., roads), and area constraints, with which a node cannot cross one or more parts of the field (e.g., no-entrance zones and obstacles).

The objective of this paper is therefore to quantitatively investigate the effect of mobility constraints on epidemic broadcast mechanisms. We evaluate the performances of epidemic broadcasts [1] — P-BCAST (PUSH-based BroadCast), SA-BCAST (Self-Adaptive BroadCast), and HP-BCAST (History-based P-BCAST) — with a random waypoint mobility model with mobility constraints. Through simulations, we investigate how the performances of epidemic broadcasts are affected by mobility constraints.

The organization of this paper is as follows. Section 2 classifies mobility constraints and introduces a mobility model with constraints called CRWP (Constrained Random WayPoint) mobility model. In Section 3, we evaluate the performances of P-BCAST, SA-BCAST, and HP-BCAST with the CRWP mobility model. Section 4 concludes this paper and discusses future works.

2 Mobility Constraints and Constrained Random WayPoint Mobility Model

Mobility constraints are classified into two categories: *path constraints* and *area constraints*. Path constraints restrict the trajectory of a node; i.e., a node has to move along one of predetermined paths (e.g., roads in VANETs). Area constraints restrict the area that a node can move; i.e., a node cannot cross one or more parts of the filed (e.g., no-entrance zones and obstacles). In this paper, we focus on path constraints since they are commonly observed in DTNs and they can easily approximate area constraints.

We extend the RWP (Random WayPoint) mobility model [2], one of the most popular mobility models, to incorporate path constraints. The mobility model is called *CRWP (Constrained Random WayPoint) mobility model*. In the CRWP mobility model, for a given set of paths (i.e., graph), every nodes moves according to the RWP mobility model except: (1) the initial position and the destination of a node are randomly chosen on a randomly-chosen path, and (2) every node moves toward its destination following the shortest-path from the current position to its destination.

3 Simulation

In this section, we evaluate the performances of P-BCAST (PUSH-based BroadCast), SA-BCAST (Self-Adaptive BroadCast), and HP-BCAST (History-based P-BCAST) with the CRWP mobility model.

3.1 Simulation Setup

P-BCAST is a simple epidemic broadcast [1, 5]. In P-BCAST, a node forwards the message whenever it encounters other nodes. Namely, a node forwards the message to other nodes, which newly enter the radio communication range of the sending node. P-BCAST achieves the optimal effectiveness (i.e., maximum coverage and minimum message delay) with the worst efficiency under infinite bandwidth [6]. P-BCAST is simple so that it has a clear drawback; i.e., P-BCAST generates an excessive amount of duplicate messages when the node density is high.

SA-BCAST and HP-BCAST are two extensions (i.e., self-adaptation and history) to P-BCAST [1]. In SA-BCAST, the forwarding probability is adjusted based on the number of duplicate messages, N_{dups}, and a node forwards only when a fraction N_{th} of neighbor nodes are changed. The forwarding probability is given by

$$p \quad = \quad \max\left(\frac{1}{c^{N_{dups}}}, min_p\right).$$

In all simulations, parameters of SA-BCAST are set to $N_{th} = 50$ %, $c = 0.01$, and $min_p = 0.01$. In HP-BCAST, using the message history, a node refrains message forwarding when the encounter node is in the history (i.e., the message was already sent to or received from the encounter node).

In simulation, we use three types of path constraints: *no constraint*, *grid constraint*, and *Voronoi constraint*. The CRWP mobility model with no constraint is equivalent to the original RWP mobility model [2]. The grid constraint is a set of evenly placed orthogonal paths; i.e., all paths are either parallel or orthogonal, and the distance between any adjacent intersections is identical. The grid constraint has been widely used in the Manhattan mobility model [7]. The Voronoi constraint is a set of paths, each of which is an edge of a Voronoi diagram [8]. The Voronoi constraint has been used in several mobility models for MANETs [9]. Note that the grid constraint is a special case of the Voronoi constraint.

Except for the mobility model, our simulation model is almost equivalent to that in [1]. Namely, 50 nodes randomly move according to the CRWP mobility model on 1000 [m] $\times$ 1000 [m] simulation field. The velocity of nodes are uniformly distributed in $[1, 2]$ [m/s]. The radio communication range of a node

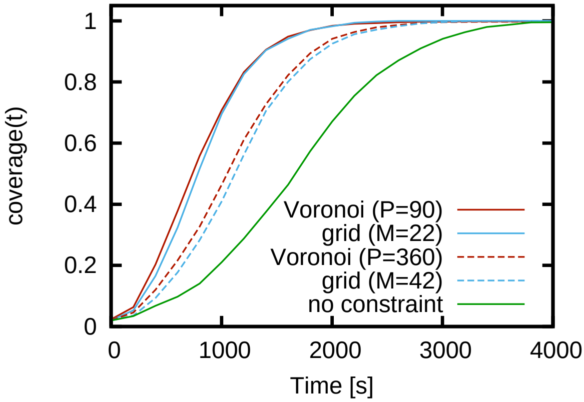

Figure 1: Evolutions of $coverage(t)$ in P-BCAST with different mobility constraints; this figure clearly indicates that existence of mobility constraint significantly improves the performance of P-BCAST.

is 10 [m]. At the initial state, only a single node (i.e., originating node) has a message and starts its message broadcast.

As a performance metric, we focus on reachability of epidemic broadcasts. We define $coverage(t)$ as the ratio of infected nodes at time t. For instance, $coverage(60)$ represents the ratio of nodes, which received the message from the originating node, to all nodes at $t = 60$ [s].

3.2 Results

First, the impact of mobility constraints on P-BCAST is investigated. The evolutions of $coverage(t)$ in P-BCAST with no constraint, grid constraint, and Voronoi constraint are shown in Fig. 1. The number of paths in the grid constraint, M, is set to 22 and 42. The number of points used for generating the Voronoi diagram in the Voronoi constraint, P, is set to 90 and 360.

Figure 1 clearly indicates that existence of mobility constraint significantly improves the performance of P-BCAST. For instance, dissemination speeds of P-BCAST with grid and Voronoi constraints are approximately 60–100 % faster than that with no constraint. Existence of mobility constraint limits the trajectory of nodes, leading a high probability of encounters among nodes. Figure 1 also shows that the amount of mobility constraint (i.e., density of paths in the simulation field) has large impact on the performance of P-BCAST. For instance, halving the number of paths in the grid constraint (i.e., from $M = 42$ to $M = 22$) increases the dissemination speed by approximately 30%.

One can find from Fig. 1 that P-BCAST with grid and Voronoi constraints show similar tendency. Namely, P-BCAST with grid constraint ($M = 22$) and

Table 1: Values of path densities with grid and Voronoi constraints; the impact of mobility constraint is well characterized by the path density.

mobility constraint	parameter	path density
grid	$M = 22$	0.0199
Voronoi	$P = 90$	0.0218
grid	$M = 42$	0.0399
Voronoi	$P = 360$	0.0394

Voronoi constraint ($P = 90$) are almost identical, and P-BCAST with grid constraint ($M = 42$) and Voronoi constraint ($P = 360$) are comparable. Such resemblance in grid and Voronoi constraints is, however, not surprising. In our simulations, parameters for the grid constraint (i.e., the number of paths, M) and the Voronoi constraint (i.e., the number of points, P) are chosen to match their *path densities*. Path density is defined as the ratio of total path lengths to the size of the field. Values of path densities with grid and Voronoi constraints are shown in Tab. 1. Figure 1 indicates that the impact of mobility constraint is well characterized by the path density.

Second, we investigate how different epidemic broadcasts (i.e., P-BCAST, SA-BCAST, and HP-BCAST) are affected with the mobility constraint. The evolutions of $coverage(t)$ in P-BCAST, SA-BCAST, and HP-BCAST with no constraint and Voronoi constraint ($P = 90$) are shown in Fig. 2.

Figure 2 illustrates that existence of mobility constraints significantly improves the performance of epidemic broadcasts regardless of the epidemic broadcast mechanism. As we have discussed above, existence of mobility constraints generally results in a high probability of encounters among nodes. With mobility constraints, all epidemic broadcasts — P-BCAST, SA-BCAST, and HP-BCAST — benefit from the increased probability of encounters.

4 Conclusion

In this paper, we have investigated the effect of mobility constraints on epidemic broadcast mechanisms in DTNs. We have evaluated the performances of P-BCAST, SA-BCAST, and HP-BCAST with the CRWP mobility model, which was an extension of the RWP (Random WayPoint) mobility model to incorporate path constraints. Our findings include that existence of mobility constraints significantly improves the performance of epidemic broadcasts, and that the impact of mobility constraints is well characterized by the path density, which is defined as the ratio of total path lengths to the size of the field.

As future work, we are planning to perform more detailed simulations of epidemic broadcasts with the CRWP mobility model. In particular, effects of several parameters — the number of nodes, the field size, the node velocity, and the radio communication range — on the performances of epidemic broadcasts

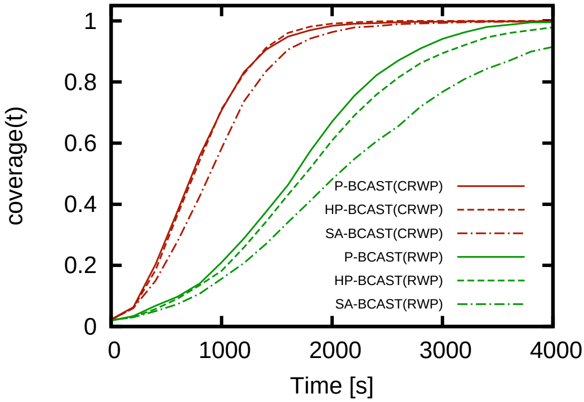

Figure 2: Evolutions of $coverage(t)$ in P-BCAST, SA-BCAST and HP-BCAST with no constraint and Voronoi constraint ($P = 90$); this figure illustrates that existence of mobility constraints significantly improves the performance of epidemic broadcasts regardless of the epidemic broadcast mechanism.

need to be examined. Mathematical analysis of epidemic broadcasts with mobility constraints would be of great value for deeper understanding of epidemic broadcast mechanisms.

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