

Encounter-based Message Broadcasting in Ad Hoc Networks with Intermittent Connectivity

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Abstract

Delay tolerant network (DTN) paradigm has been proposed to deal with message delivery in the scenarios in which network partition is part of normal network dynamics rather than abnormality. In DTN paradigm nodes could store packets and propagate it at later time. In this work we investigate its potential and compare its performance with traditional routing paradigm in which packets are only forward in space, using a realistic network model derived from network trace from current 802.11 networks. A basic application, sending broadcast messages in the network, is used to study the differences between DTN and traditional paradigms. We find that disconnection between nodes is common in current wireless networks mainly due to on-off usage patterns. In such scenario DTN paradigm has the potential of achieving 99% message delivery rate at lower delay and transmission overhead, as compared to repeated flooding in space domain. DTN paradigm also shows the strength that it does not suffer severe performance degradation even if 40% of nodes in the network are selfish and uncooperative in message forwarding. The robustness of DTN paradigm stems from the underlying SmallWorld structure of encounters in the network model.

I. Introduction

Most works on performance analysis studies on packet delivery mechanisms in ad hoc networks are done in scenarios in which nodes are always on. In this work we revisit this assumption and find that nodes display on-off usage pattern in current wireless networks. Such on-off usage pattern could significantly hinder packet delivery in the network since offline nodes can never be reached. It is also well-studied that mobility of nodes in ad hoc networks has significant influences on performance of network performances [6]. In particular, high mobility leads to quick changes in connectivity between nodes. Both on-off usage pattern and mobility pose difficulties for traditional path-based routing protocols, such as DSR or AODV, to work efficiently. These path-based routing protocols first try to find an end-to-end path to the packet receiver before sending out the message. In highly mobile scenario route discovery and maintenance becomes increasingly difficult due to frequent topology changes. In scenarios with on-off

usage pattern, nodes could be off-line and path leading to the node does not exist.

Therefore, end-to-end path based routing paradigm may not be the best one in these scenarios. The delay tolerant network (DTN) paradigm has been proposed to deal with message delivery in scenarios where network partition is a normal network dynamics rather than abnormality. In DTN paradigm, packets are sent from the sender without knowing any path leading to the receiver. Instead, the sender delivers the packet to other nodes that may have a chance to deliver the packet to the receiver at a later time. These intermediate nodes store the packets in its storage space (e.g. hard disk) and forward the packets when it encounter with other nodes. This is a different paradigm to traditional path-based routing as follows: In path-based routing paradigm packets are delivered only in space domain during a short time interval, while in DTN packets are disseminated through node mobility and pair-wise encounters and packet exchanges between nodes during a longer time frame. Time elapsed between two successive encounters can be very long since intermediate nodes store the packets for future transmissions.

In this work we revisit a simple application of delivering broadcast messages in a wireless ad hoc network. Instead of assuming always-on scenario with synthesis nodal mobility patterns, we adopt a more realistic network topology derived from wireless network traces. The network trace captures both underlying on-off usage pattern and mobility pattern of nodes. In such realistic environment, we discover that message broadcasting is no longer trivially achievable by simple flooding in space domain since off-line nodes can't be reached. Repeated flooding could be used, but it incurs high overhead to give intermediate delivery success rate. On the other hand, DTN paradigm is more suitable in this realistic setting as it increases the success rate of disseminating a broadcast message at a reduced transmission count, in comparison to traditional flooding in space domain. It also improves the waiting time before the nodes get a copy of the broadcast message. The improvement is due to the feature that intermediate nodes temporarily store copies of messages and keep looking for future transmission opportunities if the message is not deliverable at the current time. In other words, packets not only propagate in space domain by transmissions, but also propagate in time domain together with nodal movements.

The rest of this paper is organized as follows. In section 2 we discuss related work. Section 3 introduces the wireless network trace we use in this work and the direct findings about usage pattern and encounter pattern from the trace. Based on the encounter pattern derived from the trace we compare the performance of message forwarding mechanisms, and show the results in section 4. We conclude the paper and comment on future work in section 5.

II. Related Work

The delay tolerant network (DTN) paradigm has been proposed to facilitate communication in networks that loss of connectivity between nodes and network partitions are parts of normal network dynamics rather than abnormality [1][8]. In such paradigm, it is assumed that intermediate nodes store copies of messages and forward it to nodes potentially leading toward the final destination when nodal encounters provide opportunities to exchange messages. Various schemes of selecting next hop for the message have been proposed [2][3]. These previous works mainly based their analysis on synthetic mobility models (e.g. random walk).

We do not propose new schemes for selecting next hop in this delay tolerant network paradigm, but evaluate its potential using more realistic models construct from wireless network traces. Due to popularity of 802.11 wireless networks, large-scale collection of wireless network usage traces has been made possible in recent years. In this work we use the wireless network trace collected from Dartmouth University [4]. The wireless network trace reflects the combined result of user mobility and usage pattern. The trace truthfully captures the current behavior of wireless network users, based on which we derive encounters among users and evaluate the potential of adopting delay tolerant encounter-based message forwarding in such scenario. One may argue as technology evolves, the usage pattern may change and study based on current usage pattern is not adequate to predict performances of message forwarding mechanisms in future networks. We acknowledge such shortcomings but address that the trend of wireless network is moving toward higher mobility of end devices (e.g. PDAs, smart phones, etc.) and will results in more encounters among nodes. The evaluation based on network trace today will provide a baseline of comparison.

Perhaps the closest work to ours in the literature is [5], in which the authors give out PDAs to students to carry and study their encounter patterns. They capture all encounters among nodes using always-on devices, in contrast to our trace-based approach which only captures encounters when nodes are turned on. However, they mentioned in the paper one discovery of their experiment was that power consumption is still a major issue in current mobile devices. Therefore we argue that on-off usage pattern will still be unavoidable in the foreseeable future and putting usage

patterns into consideration will more realistically reflect the behavior of users. Another benefit of the trace-based approach is that it allows larger campus-wide scale study than the experiment in [5], which focus on about 20 students taking the same class.

Based on our study of the encounter patterns of mobile nodes, we find that although the encounters between mobile devices are not directly related to social closeness between their owners, the network construct by encounters is similar in structure to other social networks, displaying the SmallWorld [9][10] property. This is an encouraging observation which suggests it will not take a long path for a packet to reach its destination via intermediate mobile nodes serving as forwarders.

Mobility models and its impact on performances of path-based routing paradigm in ad hoc networks have been studied extensively in the research community. The key finding is that mobility models have significant influences on important metrics for path-based routing protocols, such as link duration and path duration [6][7], hence it impacts performance of path-based routing protocols by increasing cases of path breakages and route salvaging/maintenance operations required [11]. Mobility should also have impacts on delay tolerant encounter-based forwarding, since different mobility pattern will certainly change the frequency and duration of encounters. We do not explicitly study the influence of mobility or usage pattern may have on encounters in this paper and leave it as our future work.

The network trace we used is actually a combined result of underlying factors that may have influences on the usage pattern, such as user mobility, preferences, correlation between users, etc. Researchers are also interested in building synthesis models that capture important factors of these underlying factors the trace [12][13]. In this work we do not address these underlying factors but take the trace as a realistic, empirical model that includes all these factors and focus on the its influences on message delivery schemes. This approach is summarized in Fig. 1.

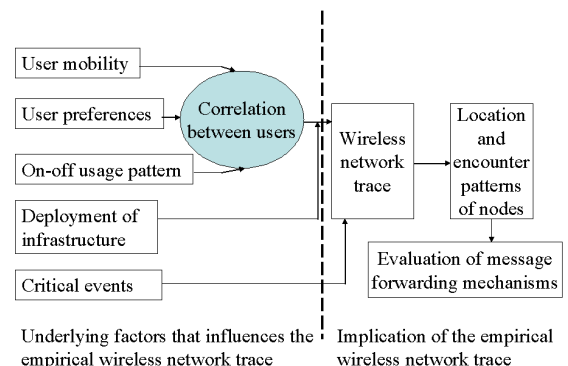


Fig. 1. The underlying factors and implication of network traces. In this work we focus on the implication part only.

III. Wireless network usage trace and encounters

3.1 Choice of wireless network trace and definition of encounter

In this work we use wireless network traces from Dartmouth University [4]. Dartmouth wireless network trace has syslog for each association/re-association/de-association events hence it is possible to obtain each node's location at access points (AP) granularity with accurate time information. Coordinates of AP is also available in the trace and in this work we use the AP coordinates to approximate the location of MNs currently associated with the AP.

We use 2-week's worth of trace from Dartmouth University between March 1st and March 14th 2004. There are totally 4618 nodes in the trace during this time frame. In this work, our analysis focus is on the online/offline patterns of mobile nodes and the encounters between mobile nodes derived from this AP association history to give insights about possibility for encounter-based forwarding given the usage pattern.

We use the following simple definition of encounters between MNs. If 2 MNs appear at the same *location* during overlapped time we refer to this as an *encounter* between 2 MNs in this paper. We choose 2 different granularities of the definition of a *location*: access point (AP) level or building level. In the former case MNs are defined as having encounters with others only when they associated with the same AP, while in the later case all MNs within the same building are defined as encountered with each other.

3.2 On-off usage pattern and spatially limited visit pattern

We first observe the on-off usage pattern from the trace. We validate our argument that most nodes are not always on by finding the CDF for online fraction of time during the 14 days trace period. In Fig. 2 we can observe that the online time fraction of mobile nodes is quite uniformly distributed, ranging from less active users who are online for only several minutes to aggressive users who are online almost all the time. There are about 65% of nodes which are online for less than 50% of total time (14 days). This supports the argument that on-off behavior is an essential characteristic of current wireless network users.

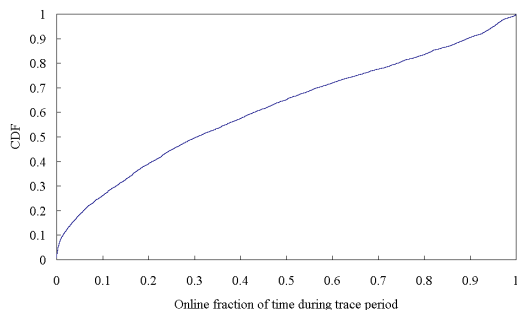


Fig. 2. CDF of online time fraction during the trace period

We also plot the number of online nodes in snapshots taken every 30 minutes through the trace period in Fig 3. We can observe clear diurnal pattern in the figure and it

matches our intuition that less users leave their devices on during late night than in the day time. While there are totally 4618 nodes observed in the whole period, in any of the snapshots at most only about half of the nodes are simultaneously online. This indicates even flooding in space domain can at most reach only half of the total population, if there is no network partition. To effectively send out a broadcast message to reach the whole population, a single trial of flooding in space domain is certainly not enough.

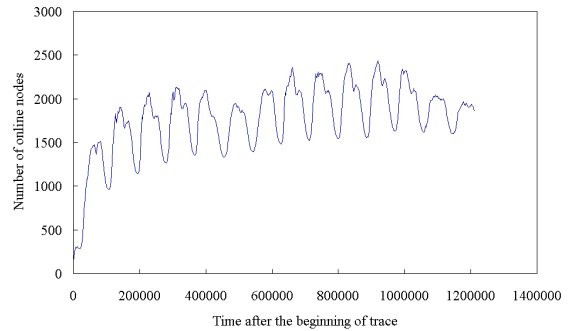


Fig. 3. Online nodes in snapshots taken every 30 minutes

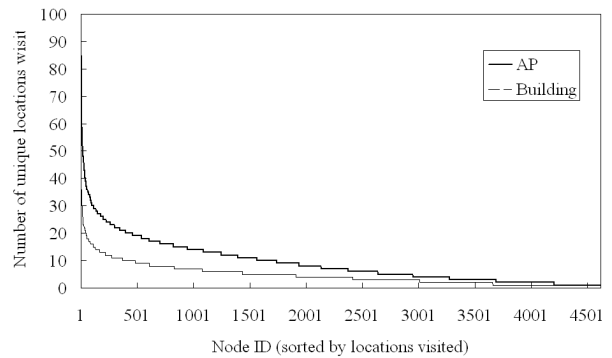


Fig. 4. Number of locations visited by each MN during the trace period, with Node ID sorted by decreasing order of total visited locations.

We further look into the number of *locations* a MN visits. It turns out that most MNs do not access a large portion of locations during the trace time frame. At AP level, among the total of 623 access points, the most aggressive MN visited 93 APs through the 2-week trace period, and on average a node visits 9.17 APs during this time frame. At building level, the most mobile MN visited 59 buildings among the total of 184 buildings on campus, and on average a node visits only 4.72 buildings during the time frame. The distributions of number of APs or buildings visited by MNs are shown in Fig. 4. The graph indicates that current wireless network users are quite spatially limited in locations where they use the devices. We consider this as a combined result of the fact that wireless devices today are not really easy to carry around (i.e. Majority of wireless network capable devices are laptop computers [4]) and typically most people do not visit all possible locations in a given environment but rather stay in several locations most of the time.

3.3 SmallWorld by encounters

Given that mobile nodes do not stay online for large time fraction, and they visit only a small portion of locations when they are online, one may doubt that it is possible to have enough encounters among mobile nodes to propagate messages. To investigate this question, we define static *encounter relationship graph* as follows: During the 2-week trace period, if 2 nodes have encountered at least once, we draw a link between them on the encounter relationship graph. This link indicates a chance to pass messages between these 2 nodes. Whether the encounters between these 2 nodes are actually utilized to propagate a message depends on the time the message being sent and the mechanism of making message-forwarding decisions. The concept of encounter relationship graph is only introduced to capture *potential* paths for messages to take in the encounter-based forwarding. Note that although the time-evolving connectivity graph formed by mobile nodes keeps changing with respect to time, the encounter relationship graph we defined only captures whether 2 nodes have encounters during the whole study time frame, and it is a stationary graph.

If the encounter relationship graph is well-connected (i.e. do not fall apart into disconnected small pieces), we can conclude that encounters provide good potential for message forwarding. The methodology we chose to analyze these encounter relationship graphs follows the SmallWorld concept introduced by Watts et al. first in [9]. SmallWorld network is widely used to study the structure of networks, including Internet topology, social networks, electricity power network, and co-work relations in several professional society [10], to name a few.

The parameters of encounter relationship graphs for 2 different definitions of location (AP or building) are shown in Table 1, together with parameters of random graph and regular graph with the same average node degree. The result of this analysis is encouraging since it indicates most MNs form a connected network with SmallWorld property (i.e. Clustering coefficient is close to that of a regular graph with the same total node and average node degree, while average path length is close to that of a random graph with the same parameters.). This implies although nodes display diurnal on-off usage pattern and spatial limitation in number of locations visited, the underlying structure of encounters among nodes still allows the possibility of forwarding messages across the network utilizing encounters alone.

We also look into the distribution of out degrees of nodes in encounter relationship graph, which is equivalent to the distribution of *unique* nodes encountered by a particular node through the trace period. From Fig. 5 we observe the complementary CDF (CCDF) of out degree in encounter relationship graph is a skewed distribution similar to the node degree distribution found in Internet and various types of networks [10]. In the context of encounter

relationship graph, this skewness implies that a small portion of nodes encounter make much more encounters than the majority of nodes do.

| Definition of location | AP | Building |
|--|---------|----------|
| Average node degree | 183.21 | 553.62 |
| # of nodes in largest connected part of graph | 4586 | 4613 |
| Clustering coefficient | 0.4293 | 0.6176 |
| Average path length | 2.3291 | 2.0037 |
| Clustering coefficient of regular graph with similar node degree | 0.7459 | 0.7486 |
| Average path length of regular graph with similar node degree | 12.5157 | 4.1634 |
| Clustering coefficient of random graph with similar node degree | 0.0401 | 0.1201 |
| Average path length of random graph with similar node degree | 1.6167 | 1.3355 |

Table 1. Parameters of encounter relationship graphs with locations defined as AP or building

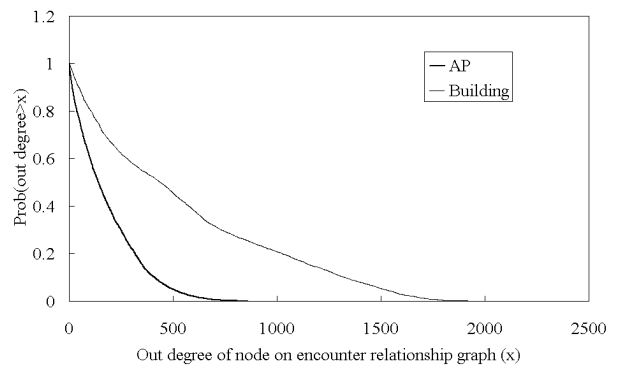


Fig. 5. CCDF of node degree on encounter relationship graph, which is equivalent to unique nodes encountered during trace period

IV. Comparison of message broadcasting mechanisms

4.1 Message broadcast mechanisms in ad hoc network

In this paper we focus on a specific type of application: Broadcasting a copy of announcement message to every node within the network. Such application can be achieved easily using single-shot flooding in a connected network when all nodes are always on. However, considering realistic on-off behavior of nodes and occasional network partitions, flooding perhaps will not give the best

performance in terms of maximizing percentage of nodes receiving the announcement message.

In this section we compare three different mechanisms of propagating broadcast messages in a network and compare their performances using network model derived from the wireless network trace. The first mechanism is simple message flooding from the sender through connected part of the network in space. This is the approach we would use to send out a broadcast message using MAC layer flooding in ad hoc network. In the work, we use the simple disk model to determine connectivity of nodes in space. If 2 nodes are within a certain threshold distance, we assume that they are able to communicate with each other through space. In the performance analysis we assume the threshold to be 200 meters, which is chosen to be larger than typical range of communication for wireless networks on purpose. Choosing this unrealistically large transmission range will give a better chance for nodes to propagate the message in space, providing an upper bound of reachable nodes by flooding in space. To overcome the problem of some nodes are off at the time when the broadcast message is sent, the sender will try to rebroadcast the message every 2 hours if it is online.

The second mechanism in the comparison is to propagate the message via encounters only. In this mechanism, the sender and nodes that already received the announcement message keep looking for potential recipient when they are online. If they encounter another node that has not got the message yet, they forward the message to the recipient. In the mechanism the message follows the nodes movement and gets disseminated via encounters. The message only gets disseminated within the current location (AP or building, depending on the definition used) of nodes that have received the message. We refer this mechanism as encounter-based forwarding below.

The third mechanism is to propagate the message in both space and time, referred as 2-dimensional forwarding below. The nodes that have received the message keep looking for recipient of the message, not only via encounter at its current location, but also in other neighboring locations in space within its 200 meter radio transmission range. Whenever a node which has not received the message appears within the transmission range, the packet holder propagates the message directly to the receiver. This mechanism is a combination of the 2 above mechanisms and is the most aggressive one. 2-dimensional forwarding can also be viewed as a generalization of encounter-based forwarding in which the range of encounter is as long as the transmission range of MNs.

We compare the three mechanisms using the following metrics. For broadcasting announcement message the metric matters most is the percentage of nodes that are able to receive the message. We also compare the overhead incurred in these mechanisms in terms of number of

transmissions made by the nodes throughout the process of delivering the message. Delay is of secondary concern in our case, but it is nice if we could have low delay, so we also look at delay statistics.

4.2 Performance evaluation of announcement mechanism

We use the following traffic patterns to compare the mechanisms for announcement message delivery introduced in last section: We pick the top 500 nodes in online time ranking as senders of announcement messages. Each of them has one announcement to send to all other nodes when they first come up online. All the nodes try to propagate these messages within the whole duration of trace, and we observe the average value of performance metrics for these 500 announcement messages. We ignore the constraints such as collision of transmission and storage space of nodes at this stage, and focus on the performance of message delivery mechanisms in ideal case.

The average number of announcement messages received for all nodes in the network and the total number of transmissions performed to deliver these messages for each mechanism are shown in Table 2. As we can observe from the figures, 2-dimensional forwarding achieves the highest message delivery rate. Encounter based forwarding at building level has performance close to 2-dimensional forwarding. Flooding in space domain, on the other hand, has low message delivery rate. The reason for flooding in space unable to deliver announcement messages with high success rate is that it fails to transmit messages at a correct time. Since the sender does not have knowledge about when the nodes still waiting to receive the announce messages become online, the best strategy it can possibly choose is to re-broadcast the messages repeatedly. However, the marginal return for periodically flooding decreases with respect to time, as shown in Fig. 6. In the figure we see that after a certain time the re-broadcast helps little to forward the announcement message to new nodes. All the effort it makes to deliver messages end up with sending redundant copies to the nodes that are constantly online and have already received the message. This is because periodical broadcasts miss those potential receivers who are not on line at sending times, and this is likely to happen for nodes which come online with small online time fraction. Of course, one could propose to shorten re-broadcast period to increase the message delivery rate. However, this introduce even more transmission count, aggravating the overhead that already makes flooding a less preferable choice among the 3 mechanisms, especially for mobile networks in which nodes have stringent power constraint.

| Forwarding mechanism | Average messages received per node | Total transmission count |
|--------------------------------|------------------------------------|--------------------------|
| Repeated flooding | 447.776 | 199566725 |
| Encounter-based AP level | 493.711 | 17335680 |
| Encounter-based building level | 497.827 | 11809936 |
| 2-dimentional | 498.726 | 4485040 |

Table 2. Comparison of performance metrics

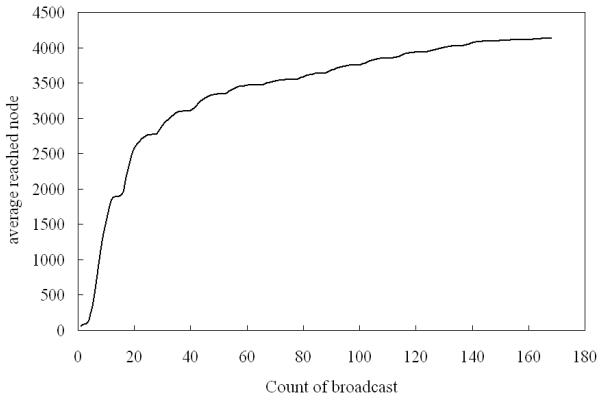


Fig 6. Average reached nodes of the 500 repeated broadcast messages increase with diminishing marginal return

Encounter based forwarding and 2-dimensional forwarding by far outperform flooding in terms of transmission count. This is due to the inherent wastage in flooding that a node can receive duplicate copies of the same message for many times in order to propagate the message in space. In the simulation above for 500 message senders, each node that has received a given message receives it for 61.8 times on average. On the other hand, in the other 2 forwarding mechanism each message is received only once for each receiver, resulting in huge reduction in transmission count. We also observe that as the transmission range reduces from 200 meter in 2-dimensional forwarding to local building and further to AP in encounter-based forwarding, the transmission count (i.e. overhead) increases.

We also show the distribution of number of message transmissions required via encounters to deliver the message. We refer this as *hop count* on end-to-end path in the encounter-based forwarding. We note that the notion of hop count here is a little different from its definition in traditional networks, since successive hops occur at different time, and a node could potentially move in the network before sending the message to the next hop. We show the averaged distribution of hop count for the 500 messages to reach each node in the network under encounter-based forwarding and 2-dimentional forwarding.

In Fig. 7 we observe that the distribution suggests a larger average path length taken by encounter-based mechanisms than that we calculated from the static encounter relationship graph. This is due to the fact that message forwarding must take the earliest available encounter since we can not predict future encounters and take advantage of available shorter path later. However, overall path length is still not very large. For encounter-based forwarding at AP level, a delivered message takes 7.60 hops on average. The average hop distance for encounter-based forwarding at building level and 2-dimentional forwarding are 5.12 and 1.95, respectively. This quantity is not available for flooding since a node may receive the same message for more than one time at different distance from its sender. However, almost all of the messages delivered by flooding reach the receiver within 3 hops. The high transmission count by flooding is not because of messages taking long path to receivers, but the fact that copies of the same message is being delivered redundantly.

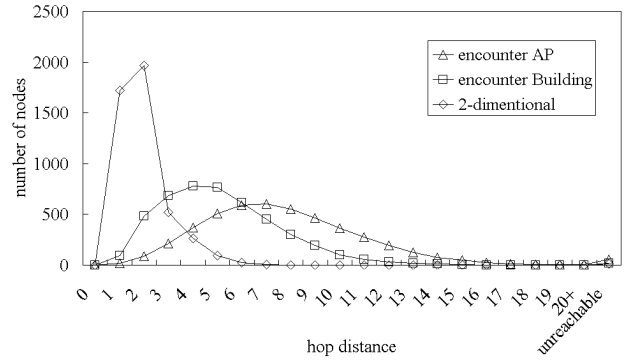


Fig. 7. Distribution of path lengths from message sender to all receivers, average for 500 senders

We also look at average delay for delivered messages in the 3 mechanisms. From the first column in Table 3 it appears that the average delays are not very different among the 3 mechanisms. However, there is a problem about directly applying the traditional definition of delay, which is simply the difference between message send time and message receive time, in networks that not all nodes are always on. The definition is problematic because if a given node is not on yet, there is no way that the message can be delivered to this node. Therefore we redefine delay as the difference between message receive time and the later of message sent time and the first online time of the receiver. The modified definition is the time a receiver must wait after it joins the network until it receives the message. Adopting this more appropriate definition of message delivery delay in on-off network, the difference between the 3 mechanisms is again apparent in the second column of Table 3. The delay of flooding is larger than the other mechanisms because messages can only be delivered by the source at fixed deliver intervals, while in the other 2 mechanisms online nodes keep watching for potential

receivers and send messages immediately if a new node comes online within transmission range of a node who already received the message.

| Forwarding mechanism | Delay (seconds) | Modified delay (seconds) |
|--------------------------------|-----------------|--------------------------|
| Repeated flooding | 183375.7 | 46158.89 |
| Encounter-based AP level | 178509.3 | 23551.53 |
| Encounter-based building level | 169496.3 | 12654.96 |
| 2-dimentional | 163660.8 | 6671.09 |

Table 3. Comparison of performance delay

4.3 Robustness of encounter-based forwarding

In this section we look further into encounter-based forwarding. Specifically, we study the impact of an issue that have been raised repeatedly as a potential problem to hinder the feasibility of a infrastructure-less network such as a wireless ad hoc network: Users may be selfish and not all of them are willing to participate in the activity of sending messages for the others. In the simulation experiment, we make a portion of users selfish such that it sends message for itself and receives message from others but never forward messages for other sources, and we study the performance degradation under this setup. We find that performance of encounter-based message forwarding is quite robust to the reduction of transmission opportunity due to user selfishness as follows.

In the following simulation we change nodes with high unique encounter count into selfish nodes. This would eliminate more transmission opportunities than pick selfish node randomly, hence introduce greater impact to performances. We show the distribution of average path length traveled by delivered messages when up to 40% of nodes are turned into selfish mode in Fig. 8. We show simulations for encounter-based forwarding at AP level only. The results for encounter-based forwarding at building level or 2-dimentional forwarding are similar. From the figure we observe that although messages are forced to take longer alternative path as number of selfish nodes increases, most messages still get through. The performance degrades gradually when the percentage of selfish node increases. The average unreachable node for a given sender increases from 58.1 to only 120.21 when selfish nodes increase from 0% to 40% and this translates to decrease of average received message from 493.711 to 486.985. At mean time, the average path length increases from 7.60 hops to 8.77 hops and delay (under the modified definition) increases from 23551.53 to 74664.32 seconds.

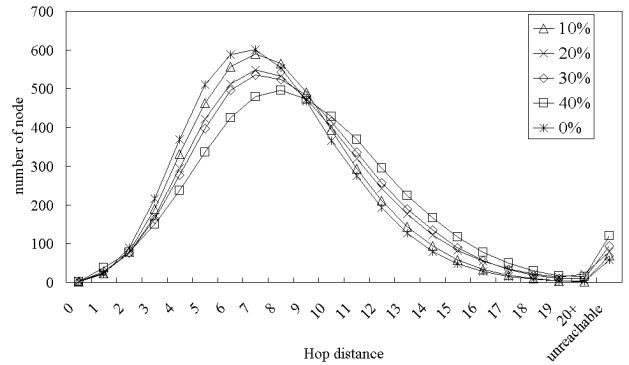


Fig. 8. Distribution of average path lengths with increasing percentage of selfish nodes

This counter-intuitive result is not so surprising since in section 3.3 we have shown that the static encounter relationship graph among nodes is a SmallWorld network. One property of SmallWorld network is its robustness in terms of connectivity against node removal. Hence in encounter-based forwarding, even if some nodes are not cooperative to forward the broadcast messages, it is still likely for the messages to reach a large portion of the network through other encounter chances. The robustness of encounter-based mechanism makes it an attractive solution in the scenario in which not every node is willing to participate in message forwarding.

V. Conclusion and future work

In this work we investigate the mechanisms of delivering broadcast messages in ad hoc network. We use a realistic wireless network trace to derive the topology of the ad hoc network, which encompasses all of underlying factors such as node movement, on-off usage pattern, etc. From the wireless network trace, we first observe on-off usage pattern is an important characteristic of current users, and flooding in spatial domain alone fails to deliver broadcast messages to the majority of nodes, even if flooding is performed repeatedly. On the other hand, delay tolerant encounter-based forwarding schemes are able to deliver messages to much larger proportion of nodes at a reduced transmission overhead. We further show performance of such encounter-based forwarding scheme does not degrade too much when an intermediate proportion of nodes are selfish. These results together make delay tolerant encounter-based forwarding a solution with good potential in challenging network scenario consists of on-off usage pattern and network partitions.

In this work we introduce encounter-based forwarding as an alternative solution under realistic network topology. We show the potential of encounter-based forwarding mechanisms under idealistic setup. In particular, we do not look into the issue of actual protocol design to achieve the potential illustrated in the paper. An intelligent message forwarding protocol could choose better next hops that lead

to the destination in fewer transmissions. We leave this part as the future work.

We also realize there is a need for new approaches to study network topology. Traditionally, network topologies are studied as static graphs. In ad hoc networks, mobility of nodes changes its topology over time. Most previous studies understand its effect by studying snapshots of topology and its rate of change. This approach is chosen because packet transmissions only occur in space domain during short time interval, in which the network topology can be safely assumed as fixed. An alternative approach to understand network topology in DTN paradigm would consider it evolves continuously with respect to time and focus our study on obtaining the important metrics that capture the characteristics of this time-variant graph. We will take this different approach to understand the influences of mobility and on-off usage pattern on encounter pattern in time-variant graph in future work.

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