Human Mobility Based Message Transfer in Delay Tolerant Networks – A Single Relay Approach

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Abstract—**A Delay Tolerant Network (DTN) is a type of Mobile Ad Hoc Network, where end-to-end connectivity between a pair of nodes may never exist. Due to this lack of end-to-end connectivity, traditional routing methods are not suitable in a DTN. However, various approaches have been proposed to achieve message transfer in such a network. This work looks into utilizing the capacity of 802.11n wireless standard, available on the modern mobile devices for this task. Modern mobile devices are equipped with multiple wireless ports as well as ever increasing processing power and storage capacity. They are not utilized as an alternative means for message transfer, even when the infrastructure-based connectivity is not available. The mobile devices move around according to the human mobility pattern, which is semi-deterministic in nature. This work studies how this semi-deterministic nature of human mobility can be effectively utilized for message transfer in a DTN environment. Simulation shows that the existing features of mobile devices are sufficient to achieve close to 100% connection opportunities.**

Keywords-*Delay Tolerant Network; Routing performance; Human mobility.*

I. INTRODUCTION

Wireless equipments are becoming part and parcel of our everyday life. The present day technology enables communication on the move. However, this requires expensive infrastructure like transmitters and receivers mounted on towers. The Internet communication also is infrastructure dependent. Both the wireless communication and internet communication assume the availability of end-to-end connectivity. Effective communication is not possible, in the absence of such end-to-end connectivity.

In a network of mobile devices, some node pairs may never meet each other or may meet each other after a long delay. This work explores how effective communication can be had among such nodes.

The 802.11n-based Wi-Fi technology has picked up significant market momentum and is available on most of the modern handheld devices. The processing power and storage capacity of these devices are also on the increase. Since they are carried by humans, the mobility of these devices follows the human mobility pattern. Various authors have studied the human mobility pattern and have found that the parameters like contact duration, inter-contact duration etc follow power law distribution [1, 2], up to a characteristic time. In addition Song et al [3] have pointed out that human mobility is 93% deterministic. These features open up a new way of communicating.

The objective of this work is to explore how the features available on the 802.11n compatible handheld devices can be utilized for effective communication among disconnected nodes, utilizing the human mobility characteristics.

II. RELATED WORKS

Many studies that required knowledge of human mobility assumed a fundamentally stochastic human movement. The Erlang's formula used in telephony and Lévy-walk models used in the study of viral dynamics are two examples among others [3]. However, recent studies showed that human mobility is not purely random. Su et al [4] conducted experiments in a campus and established that user mobility and their opportunistic pair-wise contacts can form an ad hoc network. Erramilli et al [5] showed that the contact duration and inter-contact duration for human mobility follow power law distribution with heavy tail. Other commonly used mobility models exhibit exponential decay for the distribution of these parameters. Hence they cannot be used to model human mobility. Musolesi and Mascolo [6] developed a Community Mobility Model (CMM), which is based on social network theory. The social network is an input for this mobility model. They showed that this model has the heavy tail characteristic for the contact and inter-contact duration distribution. Spyropoulos et al [7] derived an expression for the encounter time and calculated encounter-based statistics under a realistic mobility scheme. They represented the CMM by a simple 2-state Markov chain, for making routing decisions. Chaintreau et al [8] analyzed the various traces and showed the impact of various parameters of the distribution on the performance of the algorithm. The HiBOp algorithm proposed by Boldrini et al [9] collected various community information to build up the social context of each node. This context information is used for routing purpose. Boldrini et al [10] showed that such algorithms reduce congestion in the network and provide acceptable quality of service. Miklas et al [11] categorized people into friends and strangers. They showed that incorporating this social information in routing decisions improves the performance of several DTN routing protocols.

Hsu et al [12] extended the concept of CMM proposed by [7]. The new model is a time-variant community mobility model. This model captures mobility characteristics like location visiting preferences and re-appearance periods. In CMM model, a node had the preference to visit another node (person). But in this model, the preference is to visit certain places at specific times, and not to persons. The working day movement model of Ekman et al [13] intuitively depicts the movement pattern of people. They showed that this model has contact and inter-contact distribution similar to real user traces.

Daly and Haahr [14] proposed SimBet routing protocol for DTN routing. It uses the betweenness centrality metric and locally determined social similarity to the destination node, for routing. The BUBBLERap algorithm, proposed by Hui et al [15], is another social algorithm that uses community and centrality aspects of the society. The idea of correlated interaction is utilized to select forwarding paths.

The ContentPlace framework proposed by Boldrini et al [16], aims to make data reach in certain regions of a network where interested users are present. They showed that information about the social users' behavior turns out to be very efficient in achieving their aim. Their simulation results showed that social oriented policies provide significant benefits over non-social oriented policies. They also established that the policies which exploit the social role of nodes are superior.

III. MOBILITY PATTERN AS A PARAMETER

Researchers have used historical information of node encounter, context information etc to find suitable routes for message transfer in DTN. These parameters are easily measurable. However, they are highly volatile.

Song et al [3] explored the limits of predictability in human dynamics. Based on traces from mobile towers, they studied the spatiotemporal order of human mobility. They came to the conclusion that humans tend to meet the same people, at the same time, in the same place with an average predictability of 93%. This is true also of the location visiting preference. This predictability is independent of demographic factors as well as external parameters like age, gender, language groups, population density, rural or urban environment etc. It is also not imposed by the work schedule: there was no significant change in the regularity over the weekends compared to the weekdays.

This semi-deterministic nature of human mobility has three consequences:

a) people tend to meet the same people everyday,
b) people tend to visit the same places everyday and
c) the duration of time people spend in various locations tend to remain the same,

with a probability of 0.93. Hence the mobility pattern of any one day is representative of a person's daily mobility and can be used for discovering the route to a destination node.

A. Quantification of the Contact Strength

Consider a square area of size a. Node n_i is at point p_i at time t_i. Thus, formally a node can be represented as a tuple $\{n_i, p_i, t_i\}$.

Each node is assumed to have a communication range of r such that $r << a$.

When nodes move around, a node may enter into the communication range of another node. If the distance between these nodes $< r$, then they are said to be in contact. And the time they remain in contact is termed as contact duration. Thus contact duration can be formally defined as the time elapsed from a node's entry into the range of another node, until its consequent exit.

Two nodes that were in contact may meet again, after an interval. This interval is termed as inter-contact duration. Formally it is the time elapsed since the previous exit, until its next entry into the communication range of a node.

The volume of data that two nodes can transfer during a time slot, depends on the strength of the contact. The strength of a contact is a function of the total contact duration as well as the variability of the contact duration, during this time slot. Total duration of the contact is the total time they are in contact. Variability of the contact duration is the number of times they make and break the contact. A continuous contact pattern is preferred to a discontinuous contact, as it reduces the overhead associated with connection making and partial data transfer. In other words, longer contact duration and lower variability are desirable features of stronger contacts.

The total contact duration is the sum of the contact instances, in a time slot. Higher this value, more the data that can be transferred. The contact variability is measured from the coefficient of variance (CV) of the contact pattern. Lower value of CV indicates continuous contact and so stronger contact. Hence the contact strength is quantified using the formula:

Contact strength = total contact duration / CV. (1)

B. Contact Graph

The contact strength as calculated by Eq. (1) is used for the construction of the contact graph. The contact graph is a weighted graph, with link weights indicating the strength of the contacts. Two nodes are connected by a link, only if their contact strength is greater than a threshold value.

When a source node wants to send a message to another node, the algorithm that is detailed in 3.3.1 below requires the contact opportunities between these nodes as well as the contact opportunities between these nodes and other nodes. Hence, the simulation time is divided into several slots and in each slot, contact graph for each node is constructed.

Since the degree of determinism is only 93%, there is a probability of 0.07 that the path decided by this approach is not available. Alternate paths are maintained, to take care of this situation. The number of such alternate paths required, depends on the number of participating nodes.

C. Identification of Optimal Path

Since each node maintains a contact graph in each slot, it is possible to identify the slot where two nodes meet, if they ever meet. The message can be transferred during this meeting. This is the direct delivery scenario. However, this approach suffers from the following two drawbacks.

a) Low message delivery ratio, as there may not be suitable contacts between the two nodes in any of the slots.
b) High delivery latency, as the nodes may meet only at a later slot.

These drawbacks can be overcome by using relay nodes. A relay node is a node that meets the source in slot p and the destination in slot q, such that $p < q < r$, where r is the slot where the nodes directly meet.

1)Algorithm to Find the Optimal Path

The following assumptions are made.

- The simulation time is divided into n equal slots of duration t.
- The source generates the message in time slot 1.

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Check if the source meets the destination in any slot.
If the meeting takes place in the 1st or 2nd slot,
    Handover the message directly.
Endif.
If the meeting takes place in a later slot, say slot m,
    Check if the destination meets other nodes (intermediary
    nodes), before slot m.
        If there are intermediary nodes,
            Arrange them in ascending order of slot number.
            Check if any of them meets the source in an
            earlier slot.
                If yes, they are relay nodes.
                Handover the message to the first relay node.
                If no, there are no relay nodes.
                Only direct delivery is possible.
            Endif
        Endif.
    Endif.
Endif
If the source and destination never meet,
    Check if the destination meets other nodes (intermediary
    nodes).
        If there are intermediary nodes, find if any of them
        meets source in an earlier slot.
            If yes, they are relay nodes.
            Handover the message to the first relay node.
            If no, there are no relay nodes.
            Message delivery fails.
            Endif.
        Endif.
Endif.
```

D. Calculation of Delivery Ratio

Delivery ratio is the fraction of the messages that reaches the destination. In this simulation, it is assumed that all nodes have sufficient buffer area and energy to function as relay nodes. Every node generates a message to every other node. A source node with a message is able to deliver it to the destination node, if the destination node is reachable either directly or through a relay node, satisfying the threshold conditions. Such opportunities are counted, to calculate the delivery ratio.

E. Calculation of Delivery Duration

The above algorithm gives the earliest slot for handing over the message. In the best case, the message generation and the message handover takes place in the same slot. If the message handover takes place in a later slot, it entails a delay. This delay can be calculated as follows.

Let the message handover for the i^{th} message take place in slot s_i.

Width of each slot = t time units.
Delivery duration = $s_i * t$ time units.
Delivery delay = $(s_i - 1) * t$ time units.

IV. EXPERIMENTAL RESULTS AND DISCUSSION

The communication opportunities for various values of communication range and threshold values were simulated using Matlab. The synthetic mobility trace available from North Carolina State University [17] was used for the same. Two scenarios of different node density were set up, to compare the effect of node density on contact opportunities. The first scenario consisted of 50 participating nodes in an area of 2000 x 2000 square meter. The second scenario had a higher node density with 50 nodes in an area of 1000 x 1000 square meter. The simulation was carried out for 12 hours, in both scenarios.

The simulation time was divided into slots of 10 minutes each. In each slot, the contact pattern for various values of communication range was tested. Most of the modern handheld devices are equipped with IEEE 802.11n wireless port, which provides an outdoor range of 250 m and an indoor range of 70 m [18]. Keeping this in mind, the communication range was varied from 40 m onwards, to identify the range at which over 95% of data transfer can occur. For each value of communication range, the threshold value was varied from 50% to 100%. This is to study the delay in message transfer for various node densities, as well as to understand the minimum range required to transfer over 95% of messages.

A. Analysis of Communication Delay

Shin et al [19] have compared the average message delivery delay for various DTN routing schemes. Their Scale Free Routing (SFR) algorithm, using Levy Walk, closely resembles this approach. The average delay observed in SFR algorithm was compared with this proposed approach under the same simulation parameters. The result is plotted in fig.1. The model proposed in this work uses 802.11n standard and hence operates with communication range below 250 m. It is seen that, in this range, the proposed model outperforms the SFR model. When the range of communication is 250 m, and the threshold is 80%, the message delivery delay of the SFR algorithm is around 40% more than that of the human mobility based routing approach.

1) Calculation of Delivery Delay

The delay experienced by each packet is different. The average delay experienced by a packet is calculated as the average of the sum of delays, experienced by the packets that were successfully delivered.

Average delay = ∑delivery time of the delivered packets/number of packets delivered.

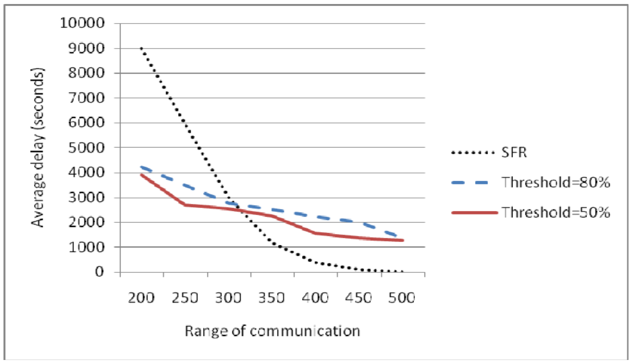

Fig. 1. Average message delivery delay for various values of communication range

B. Analysis of Delivery Ratio

The delivery ratios in both the scenarios were also studied to find out the minimum range required to attain a message transfer of over 95%. Fig. 2 shows the communication opportunities for scenario 1, which has a low node density. It is seen that in such a scenario, almost 95% of nodes are able to communicate with each other, when the communication range is 100 m and the threshold is set at 80%. Fig. 3 illustrates the effect of increasing the node density to 50 nodes in an area of 1000 x 1000 square meter. When the node density is increased, 95% of delivery ratio was achieved with a communication range of 70 m.

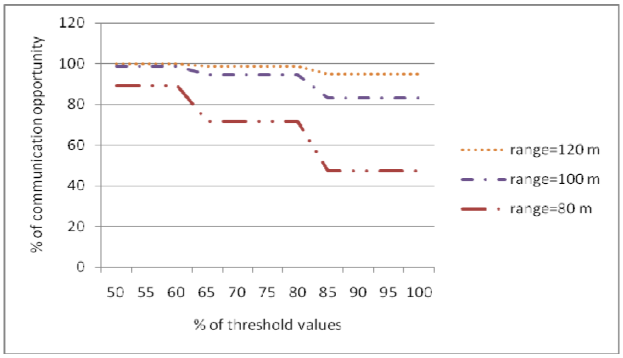

Fig. 2. Communication opportunity with 50 nodes in 2000 m x 2000 m area

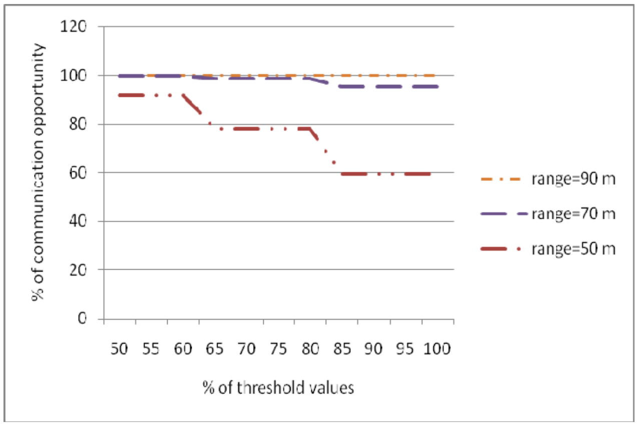

Fig. 3. Communication opportunity with 50 nodes in 1000 m x 1000 m area

These results imply that participation of 50 persons in 1 square kilo meter area enables 95% of communication.

V. CONCLUSION

Wireless equipments carried by humans can be utilized to transfer messages in a delay tolerant fashion. The message transfer opportunities depend on several parameters like the user-set threshold value of the link weight, the communication range of the mobile equipment, number of hops permitted by the algorithm, number of participating nodes and so on. It is found that utilizing the communication range offered by 802.11n standard, and a node density of 50 nodes in 1 square km area, over 95% of nodes can communicate with each other.

REFERENCES

[1] P. Hui, A. Chaintreau, R. Gass, J. Scott, J. Crowcroft and C. Diot, "Pocket Switched Networking: Challenges, Feasibility and Implementation Issues", in proceedings of Second International IFIP Workshop, 2005, pp. 1-12.

[2] T. Karagiannis, J. L. Boudec and M. Vojnovic, "Power Law and Exponential Decay of Inter Contact Times between Mobile Devices", in MobiCom'07, 2007, pp. 183-194.

[3] C. Song, Z. Qu, N. Blumm and A. Barabasi, "Limits of Predictability in Human Mobility", Science, Vol. 327, No. 5968, 2010, pp. 1018-1021.

[4] J. Su, A. Chin, A. Popivanova, A. Goel and E. Lara, "User Mobility for Opportunistic Ad-Hoc Networking", WMCSA, 2004, pp. 41-50.

[5] V. Erramilli, A. Chaintreau, M. Crovella and C. Diot, "Diversity of Forwarding Paths in Pocket Switched Networks", Internet Measurement Conference, 2007, pp. 161-174.

[6] M. Musolesi and C. Mascolo, "A Community Based Mobility Model for Ad Hoc Network Research", in REALMAN '06: Proceedings of the 2nd international workshop on Multi-hop ad hoc networks: from theory to reality, 2006, pp. 31-38.

[7] T. Spyropoulos, K. Psounis and C. S. Raghavendra. "Performance Analysis of Mobility-Assisted Routing", in Mobi-Hoc, 2006, pp. 49-60.

[8] Chaintreau, P. Hui, J. Crowcroft, C. Diot, R. Gass and J. Scott, "Impact of human mobility on opportunistic forwarding algorithms", IEEE Transaction on Mobile Computing, Vol. 6, No. 6, 2007, pp. 606-620.

[9] Boldrini, M. Conti, J. Jacopini and A. Passarella, "HiBOp: A History Based Routing Protocol for Opportunistic Networks", in WOWMOM, 2007, pp. 1-12.

[10] Boldrini, M. Conti and A. Passarella, "Impact of Social Mobility on Routing Protocols for Opportunistic Networks", WOWMOM, pp. 1-6, 2007.

[11] G. Miklas, K. K. Gollu, K. K. W. Chan, S. Saroiu, P. K. Gummadi. and E. Lara. "Exploiting Social Interactions in Mobile Systems", in Ubicomp, 2007, pp. 409-428.

[12] W. J. Hsu, T. Spyropoulos, K. Psounis and A. Helmy, "Modeling Time-Variant User Mobility in Wireless Mobile Networks", in INFOCOM, 2007, pp. 758-766.

[13] F. Ekman, A. Keranen, J. Karvo and J. Ott, "Working Day Movement Model", Mobility Models, 2008, pp. 33-40.

[14] E. M. Daly and M. Haahr, "Social Network Analysis for Routing in Disconnected Delay-Tolerant MANETs", in MobiHoc, 2007, pp. 32-40.

[15] P. Hui, J. Crowcroft and E. Yoneki, "Bubble Rap: Social-based Forwarding in Delay Tolerant Networks", in MobiHoc, 2008, pp. 241-250.

[16] Boldrini, M. Conti and A. Passarella, "Contentplace: Social-aware Data Dissemination in Opportunistic Networks", in MSWiM, 2008, pp. 203-210.

[17] North Carolina State University, Human Mobility Model and DTN Group, available online at http://research.csc.ncsu.edu/netsrv/?q=content/human-mobility-models-download-tlw-slaw, downloaded on 24-08-2010.

[18] IEEE Standards Association, available online at http://standards.ieee.org/getieee802/download/802.11n-2009.pdf, downloaded on 01-12-2010.

[19] M. Shin, S. Hong and I. Rhee, "DTN Routing Strategies using Optimal Search Patterns", CHANTS '08, 2008, pp. 27-32.

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