

Levy Walk Based Multi-Hop Data Forwarding Protocol for Opportunistic Mobile Phone Sensor Networks

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Abstract—Unstable link connectivity due to dynamic mobility nature of mobile phone users and error prone wireless link quality increases end-to-end delay for mobile phone based opportunistic network applications. This problem becomes more worse in the presence of large amount of data transmission, like multimedia data. This paper refers to Levy walk based multi-hop data forwarding protocol called Data Transmission Time and Human Walk Velocity (DTT-HWV) for Opportunistic Mobile Phone Sensor Networks (OMPSN). This paper, in particular evaluates the performance of proposed protocol in terms of end-to-end waiting time to receive data, which is an important QoS requirement for data transmission in opportunistic networks. The proposed protocol DTT-HWV reduces end-to-end waiting time to receive data compared to Random Progress (RP) data forwarding method in presence of low battery power and high path loss. Obtained results are helpful in designing and building of large scale data retrieval services for opportunistic networks involving humans in the communication network loop.

I. INTRODUCTION

Smart phones embedded with rich media sensors (camera and microphones) are initiating development of ubiquitous mobile sensing applications [1]. As smart phones are attached to human users, their unpredictable mobility movements create an opportunistic network [2] scenario which usually lacks presence of end-to-end path for routing data between source and destination mobile phone devices. Transmission of large scale multimedia sensor data (audio, video) is usually affected by unstable routes caused by topological dynamic mobile networks. This paper discusses multi-hop data forwarding protocol for Opportunistic Mobile Phone Sensor Networks (OMPSN) based on Levy walk (LW) [3], [4], [5] mobility model. We assume mobile phones communicate with each other using IEEE 802.11 ad-hoc mode [6]. Proposed data forwarding protocol is applicable to scenarios like disaster relief and military activity fields, where infrastructure or centralized data communications are not available to use.

Random waypoint (RWP) [7], [8] is the standard mobility model used in most of the research work for evaluating the performance of routing protocols in mobile networks. Unlike LW, RWP mobility model does not depict the statistical similarities with human mobility patterns, so LW has been a choice for realistic mobile networks simulation [3], [4], [5],

[9], [10]. The analytical description of LW mobility model is given in section II(C). We use LW mobility model given in [9] for the simulation of proposed work. Human inter-contact times (ICT) follows power-law distributions [3], [4], [5]. Under Truncated Levy Walk (TLW), which is a simple LW mobility model, the impact of heavy-tail flight distribution on routing protocols for mobile networks is discussed in paper [3] and [4]. Heavy-tail flight distribution of LW results in heavy-tail delays for mobile routing protocols [3]. As LW mobility parameter α value decreases (section II(C), $0 < \alpha < 2$), mobile networks becomes more dynamic and vice-versa [4].

In this paper we evaluate the contact opportunities in terms of expected waiting time to get a neighbor mobile node (or frequency of contacting a neighbor mobile node). In particular we analyse the expected end-to-end waiting time to receive data in OMPSN, constrained over application, network and LW mobility model parameters. Geographic or location aware data forwarding [11], [12] techniques is used when the network topology is dynamically changing. We propose a simple data forwarding protocol based on data transmission time and human walk velocity called DTT-HWV. We compare proposed data forwarding protocol with random progress (RP) [12], [13] data forwarding method, where data sending node selects randomly one of its neighbor node which is having forward progress and overcomes the trade off between progress and transmission success. The simulation results shows that DTT-HWV performs better than RP data forwarding method in terms of end-to-end waiting time to receive data in OMPSN.

The remainder of this paper is organized as follows. Section II describes system model for the proposed work. Section III gives description of proposed work. Section IV discusses evaluation of simulation results and Section V concludes the paper.

II. SYSTEM MODEL

This section provides the description of models used for the development of proposed work.

A. Radio Propagation Model

Friis free space equation [14] is given in equation (1), where $P_r(d)$ is received power at distance d from the transmitting source node. P_t , G_t and G_r are transmitted power, transmitter gain and receiver gain respectively. λ is wavelength of transmitted wave.

$$P_r(d) = P_t G_t G_r \frac{\lambda^2}{(4\pi d)^2} \quad (1)$$

B. Received Signal Strength Model

The equation to obtain received signal strength (RSS) in dB [14] is given in equation (2), where $P_r(d_0)$ is received power at reference distance d_0 in dB and η is path loss exponent parameter.

$$RSS = P_r(d_0) + 10\eta \log \frac{d_0}{d} \quad (2)$$

C. Levy-Walk Mobility Model

Human walk patterns closely follow LW patterns [3]. LW are optimal way to search targets which is similar to animal foraging patterns [15]. A step in LW mobility model is represented by four variables ($l, \theta, \Delta t_f, \Delta t_p$) [3], [4]. Flight is defined as straight line trip without direction change or pause. l is length of flight, drawn from power law distribution with parameter α and its probability density function [3] is given in equation (3). l_{min} and l_{max} are minimum and maximum flight length. At the beginning of each flight, LW node chooses a direction with angle θ randomly from a uniform distribution within range $[0, 2\pi]$. Δt_f [3] is flight time, the time taken by LW nodes to complete the flight length and is given in equation (4). κ and ϱ are constants. Δt_p is pause time, drawn from power law distributions with parameter β and its probability density function [3] is given in equation (5). t_{pmin} and t_{pmax} are minimum and maximum pause time. The levy distribution [3] is given in equation (6), where s and a are scale factor and exponent parameter respectively.

$$p(l) \propto \frac{1}{|l|^{1+\alpha}}, l_{min} < l < l_{max}, 0 < \alpha < 2 \quad (3)$$

$$\Delta t_f = \kappa l^{(1-\varrho)}, 0 \leq \varrho \leq 1 \quad (4)$$

$$p(\Delta t_p) \propto \frac{1}{|\Delta t_p|^{1+\beta}}, t_{pmin} < \Delta t_p < t_{pmax}, 0 < \beta < 2 \quad (5)$$

$$f_X(x) = \frac{1}{2\pi} \int_{-\infty}^{+\infty} e^{-itx - |st|^\alpha} dt \quad (6)$$

D. Battery Power Drain model

Battery power drain of mobile phones depends on individual user usage patterns. We considered typical mobile phone applications like talking, audio playback, video playback, web browsing, idle time and their power usage rating [6], [16] for obtaining minimum and maximum battery power (γ_{min} and γ_{max}) drain range, at regular intervals of time bt . γ is chosen randomly within the range $[\gamma_{min}, \gamma_{max}]$. We propose a battery power drain rate model, described in equation (7) and (8). B_{bt_2} is battery power at time bt_2 and B_{bt_1} is residual battery power at time bt_1 ($bt_2 > bt_1$). Equation (7) gives battery power

consumed for transmitting or receiving of data (B_{tx_rx}) and battery power consumed for GPS activity (B_{GPS}).

$$B_{Fdata} = B_{tx_rx} + B_{GPS} \quad (7)$$

$$B_{bt_2} = B_{bt_1} - (\gamma + B_{Fdata}) \quad (8)$$

To evaluate the proposed work the following assumptions are made. OMPSN consists of an IEEE 802.11 single channel ad-hoc network of mobile phones [14], [17] (mobile phones also called as mobile nodes). Let N be the number of mobile nodes in a communication network area A . Communication range of mobile nodes is given by r . Simulation duration is represented by d_t . We consider two regions inside area A called as $Target_{region}$ and $Data_{region}$, given by their center location points and range. Our objective is to analyse end-to-end waiting time, which is the time taken to send data from $Data_{region}$ to $Target_{region}$, under LW mobility model and is represented by term TRRT ($Target_{region}$ Reach Time). For simplifying the performance evaluation of proposed work, we consider only single source data transmission event. We use parameters Δ , $LQ_{threshold}$ and $BP_{threshold}$, where $r - \Delta$ distance is used to find mobile nodes which have the possibility of moving out of communication range during data transmission, $LQ_{threshold}$ is the threshold duration to sustain bad link quality and $BP_{threshold}$ is the required threshold battery power for a mobile node. We assume relay node will not forward data to its neighbor node (next relay node) until it receives complete data successfully and data transmission time which is in order of several seconds. We assume that mobile phones are embedded with GPS for location information and media sensors.

III. PROPOSED DATA FORWARDING PROTOCOL DESCRIPTION

This section describes expected time to get a neighbor and proposed data forwarding protocol under LW mobility model.

A. Expected Waiting Time to Get a Neighbor Node Under LW Mobility Model

Low node density and low communication range both parameters have a negative impact on end-to-end delay in opportunistic mobile networks. For OMPSN, it is very difficult to provide appropriate end-to-end waiting time to receive data, as mobile phone users mobility is unpredictable. To analyse TRRT, we require expected time to get a new neighbor (E_N) node to forward data. E_N is calculated for given N , A , d_t , and r . Location trajectory of node i ($i = 1, 2, \dots, N$) is recorded for time t_i at regular interval and corresponding counter variable n value is incremented whenever it meets a new node (node which is not visited perviously) within its range. E_N is calculated using equations (9), (10) and (11). $t_i(n)$ is the time when i^{th} node meets n^{th} new node. E_i is the i^{th} node expected waiting time to get its neighbor node.

$$WT_i = \begin{cases} t_i(n) - t_i(n-1), & \text{if } n > 1; \\ t_i(1), & \text{if } n = 1; \end{cases} \quad (9)$$

$$E_i = \mathbb{E}(WT_i) = \sum_{n=1}^{N-1} \frac{WT_i}{n} \quad (10)$$

$$E_N = \mathbb{E}(E_i) = \sum_{i=1}^N \frac{E_i}{N} \quad (11)$$

B. One-Hop Waiting Time (W_t)

We assume fixed packet size. The time required for a data packet to reach the one-hop neighbor node [17] is given by T_{p_d} (packet delivery time). Overall packet delivery time between pair of mobile nodes is given in equation (12) which gives required minimum inter-contact time (ICT_{min_tx}). We ignore RTS/CTS and small control packets (to exchange location, battery power information) transmission time as we consider data transmission for several seconds between pair of mobile nodes. W_t is one-hop waiting time to receive overall packets, T_{t_x} is transmission time, T_{p_p} is propagation time and O_p is total number of packets.

$$\begin{aligned} T_{p_d} &= T_{t_x} + T_{p_p} \\ W_t &= O_p * T_{p_d} \\ &= ICT_{min_tx} \end{aligned} \quad (12)$$

C. Expected Total Waiting Time (ETW_t)

The expected total waiting time (ETW_t) required for all the data packets to reach the $Target_{region}$ [17] is given in equation (13). h is minimum number of hops, T_{p_s} is processing time and E_N is time spent by nodes after receiving overall data packets, and the time within which LW nodes are expected to get a new neighbor (equation (11)) for given N , A , d_t and r . $h = \frac{D}{r}$, where D is distance between center of $Target_{region}$ and center of $Data_{region}$ and r is range of mobile node. From equation (13), when E_N is minimum say $E_N \approx 0$, minimum end-to-end waiting time (TW_{t_min}) bound for users to receive data is obtained from equation (14).

$$ETW_t = h * (ICT_{min_tx} + T_{p_s} + E_N) \quad (13)$$

$$TW_{t_min} \approx h * (ICT_{min_tx} + T_{p_s}) \quad (14)$$

D. Proposed Data Forwarding Protocol DTT-HWV for OMPSN

The communication range r of mobile node is divided into several regions (Figure 1) based on data transmission time and velocity of human walk (DTT-HWV). We assume maximum human walk velocity is one meter/second [18] and data transmission time (in order of several seconds) is equal to ICT_{min_tx} (equation (12)). For example, if $ICT_{min_tx} \approx 19$ seconds, then radius of a region is equal to 19 meters. To simplify the algorithm, ICT_{min_tx} should be less than $\frac{r}{2}$. The range of $Region1$ and $Region3$ are equal to ICT_{min_tx} . The three regions area and their range are given in equation (15), (16) and (17).

$$\begin{aligned} Region1 &= \pi * ICT_{min_tx}^2, \\ 0 < Region1 &\leq ICT_{min_tx} \end{aligned} \quad (15)$$

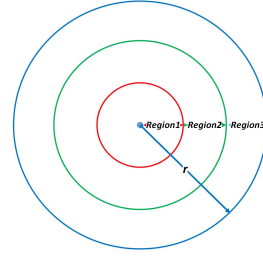


Fig. 1. Division of radio range of a node into three regions

Simulation area A	1020 m * 1020 m
Simulation duration d_t	1020 seconds
Flight parameter α	1.0
Pause parameter β	1
Average flight length	5-1020 meters
Pause time	3-6 seconds
Mobile node density N	100-700
Location sample interval	1 second
Frequency (IEEE 802.11)	2442 MHz
Transmission power (IEEE 802.11)	15 dBm
Receiver sensitivity	-68 dBm
Path loss exponent value η	2
Battery rating	3.7 * 1650 mAh
Value of $BP_{threshold}$	20% of battery rating
Battery drain range γ	[0.1, 10] mW at every one second
$B_{tx_rx} + B_{GPS}$	1 mW at every one second
Packet size	1000 Bytes
Assumed P_p	0.5 seconds
Value of Δ	5 meters
Value of δ_{tx}	0.3 dBm
Value of $LQ_{threshold}$	4 seconds

TABLE I
SIMULATION PARAMETERS

$$\begin{aligned} Region2 &= \pi * (r^2 - 2 * r * ICT_{min_tx}), \\ ICT_{min_tx} < Region2 &\leq (r - ICT_{min_tx}) \end{aligned} \quad (16)$$

$$\begin{aligned} Region3 &= \pi * ((2 * r * ICT_{min_tx}) - ICT_{min_tx}^2), \\ (r - ICT_{min_tx}) < Region3 &\leq r \end{aligned} \quad (17)$$

Data transmission is successful if data transmitting and receiving nodes are in the range for given ICT_{min_tx} duration. Proposed data forwarding protocol pseudocode to obtain TRRT is given in Algorithm 1. Required input parameters are explained in system model (section II). If the mobile nodes are chosen as relay nodes which are in the range of $Region1$, it may lead to negative progress [11], [19]. If relay nodes are chosen from $Region3$, there may be possibilities for node to move out of communication range, leading to link disconnection errors. Increase in link disconnections will increase number of retransmissions and TRRT. Therefore, first preference is for choosing relay node belonging to $Region2$, which neither leads negative progress or link disconnection errors. When mobile nodes are moving out of communication range, data sending node transmission power is increased by δ_{tx} to reduce number of link disconnections.

IV. SIMULATION RESULTS AND DISCUSSION

In this section we discuss the performance evaluation of proposed work. Each result point in the plots are the average

Algorithm 1 : Pseudocode of Proposed Data Forwarding Protocol

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1: Choose any node  $S \in Data_{region}$  at any given time  $t_{start}$ ,  $S \in N$ 
2:  $sim\_time = t_{start}$ 
3: while ( $sim\_time \leq d_t$  and  $S \notin Target_{region}$ ) do
4:   Randomly pick any neighbor node  $j$  of  $S$  where  $j \in N$ 
5:   Let distance of  $S$  to center location of  $Target_{region}$  be  $S_d$ , distance of  $j$  to center location of  $Target_{region}$  be  $j_d$  and residual battery power of node  $j$  be  $B_j$ 
6:   if ( $j_d < S_d$  and  $j \in Region_2$  of  $S$  range) then
7:     for  $i \leftarrow 1, ICT_{min\_tx}$  do
8:       if (Bad link quality duration  $< LQ_{threshold}$  and  $B_j > BP_{threshold}$ ) then
9:         Forward data from node  $S$  to  $j$ 
10:         $flag = 1$ 
11:       else
12:         $flag = 0$ 
13:       break
14:       end if
15:     end for
16:   end if
17:   if ( $j_d < S_d$  and  $j \in Region_3$  of  $S$  range) then
18:     for  $i \leftarrow 1, ICT_{min\_tx}$  do
19:       if ( $j$  distance to  $S > r - \Delta$ ) then
20:        increment transmission power of  $S$  by  $\delta_{tx}$ 
21:       end if
22:       if (Bad link quality duration  $< LQ_{threshold}$  and  $B_j > BP_{threshold}$ ) then
23:        Forward data from node  $S$  to  $j$ 
24:         $flag = 1$ 
25:       else
26:         $flag = 0$ 
27:       break
28:       end if
29:     end for
30:   end if
31:   if ( $flag \neq 0$ ) then
32:      $S = j$ 
33:   end if
34: end while

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of thirty simulation runs and parameters considered for simulation are given in Table 1. Figure 2 shows E_N with respect to varying α and N . From Figure 2, it is seen that, as N increases, time gap to contact new neighbors in the network decreases. Considering low value for α causes highly dynamic mobile networks [3], [4] as the average velocity of mobile nodes increases and vice-versa. Therefore for $\alpha = 0.2$, E_N is low and for $\alpha = 1.8$, E_N is high (Figure 2). Figure 3 plots TRRT versus ICT_{min_tx} for DTT-HWV and RP data forwarding protocols. We fixed N to 500 and ICT_{min_tx} between 5 to 65 seconds (which is less than half of obtained range of mobile node). All mobile nodes are initialized with full battery power at the start of the simulation. It is shown in

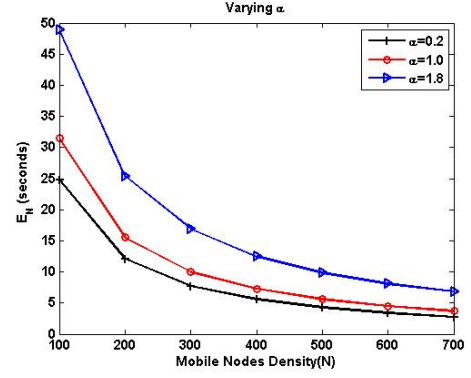


Fig. 2. E_N values for varying α values

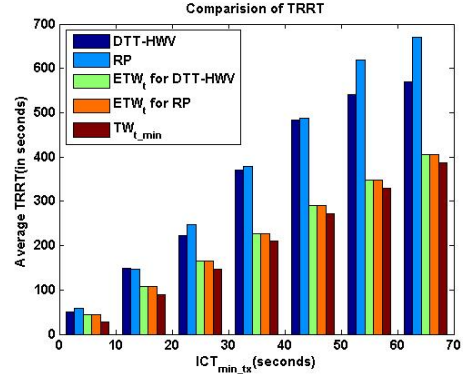


Fig. 3. Comparison of TRRT with varying ICT_{min_tx}

Figure 3 that average $TRRT$ values for DTT-HWV and RP forwarding methods are much higher than ETW_t (equation (13)) and TW_{t_min} (equation (14)). This is due to the effect of choosing a neighbor node randomly and unpredictable nature of human mobility patterns. It is also observed in Figure 3 that proposed protocol DTT-HWV gives better performance than RP data forwarding method for high ICT_{min_tx} values. In RP data forwarding method there are chances for occurrence of backward progress (due to high ICT_{min_tx} values) and also chances for choosing end nodes as data forwarding nodes, which increases network disconnection rate and TRRT. In DTT-HWV, backward progress and link disconnection rate are reduced by giving first preference to choose data forwarding mobile nodes that belongs to $Region_2$. Figure 4 shows total battery power consumed during data forwarding (B_{Fdata}) (equation (7)) versus ICT_{min_tx} . From Figure 4, it is shown that, increase of transmission power (δ_{tx}) for the proposed protocol does not consume battery power more than RP data forwarding method. Figure 5 shows average number of hops used during data forwarding. Minimum number of hops h (section III(C)) is represented by Min_no_hops . From Figure 5 performance of RP and DTT-HWV data forwarding methods in terms of average number of hops used, is not distinguishable. It is due to dynamic and unpredictable mobility nature of mobile phone users. Figure 6(a) and 6(b) shows low battery power and high path loss effect on TRRT. We

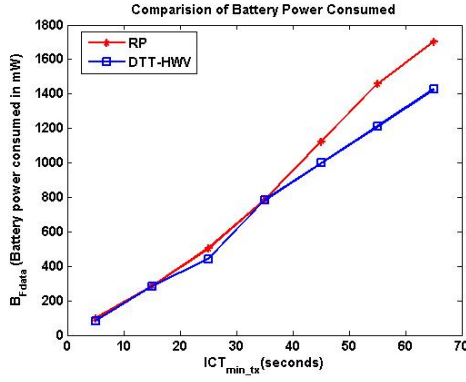


Fig. 4. Battery power consumed

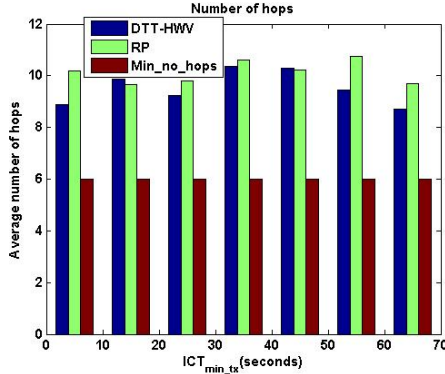


Fig. 5. Average number of hops

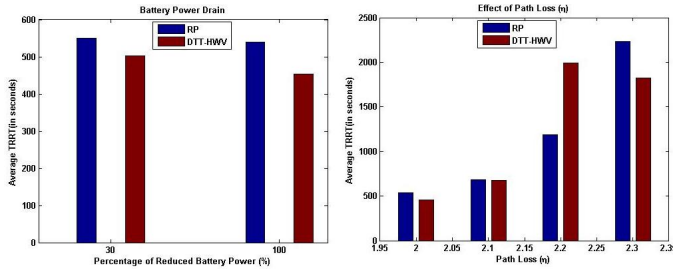


Fig. 6. (a) Battery power drain (b) Path loss effect on average TRRT

consider $N = 400$ and ICT_{min_tx} is 51 seconds. Figure 6(a) shows the average $TRRT$ values when all nodes are initialised with full battery power (100%) and randomly initialised with less than 30% of battery power at the start of simulation run. Very low residual battery power of mobile nodes increases data transmission failure rate, which leads to increase of average $TRRT$ for both proposed and RP data forwarding protocols (Figure 6(a)). Figure 6(b) shows that average $TRRT$ increases with the increment of path loss exponent parameter η for the proposed and RP data forwarding protocols.

V. CONCLUSION

For the given application, network and mobility model parameters, end-to-end waiting time (TRRT) to receive data is analysed for the proposed data forwarding protocol DTT-

HWV. DTT-HWV method has better performance as it reduces the number of link disconnections in the network and maintaining positive progress data forwarding towards target region. As Levy walk mobility model parameter α increases, expected time to get a neighbor node, E_N also increases. Due to unpredictable and dynamic mobility nature of human walk pattern, end-to-end waiting time to forward data towards the target region is more than expected target reach time ETW_t . To overcome the effect of battery power drain and high path loss problems in opportunistic networks, mobile phone users walking duration and their density in the application area should be high enough. Our future work involves developing dynamic data forwarding protocol for OMPSN.

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