Delay Optimization in Networks Using PEAR Algorithm

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Abstract— According to our simulation, potential-based entropy adaptive routing (PEAR) has achieved high delivery rate on a wide range of mobility entropy, while link-state routing has worked well only at small entropy scenarios and controlled replication-based routing only at large entropy environments. Many message routing schemes have been proposed in the context of delay tolerant networks (DTN) and intermittently connected mobile networks (ICMN).

Index Terms— Delay Optimization Networks, Mobility Entropy, Community- Structured Environment, Potential-Based Routing.

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1 INTRODUCTION

The communication paradigm of delay and disruption of tolerant networks (DTN) such as hop-by-hop application message delivery, is promising in many fields especially where stable Internet connectivity is not available (e.g., communication in disaster-affected areas, developing regions, wildlife tracking and wireless sensor networks). It has also been discussed in the context of intermittently connected mobile networks (ICMN), where an end-to-end connected path rarely or never exists because of highly dynamic properties of topology changes and node mobility.

DTLS has adopted link-state routing for communication among villages in developing regions. MaxProp and RAPID discussed message delivery among city buses. PROPHET and SOLAR focused on particular sociological mobile scenarios and evaluated their proposed routing schemes on them. Random waypoint mobility (RWP) has been widely used for evaluation of message routing in ICMNs. These works commonly focus on their particular environments with regard to mobility complexity to discuss their proposed routing schemes.

Community-structured environment (CSE) is for evaluating routing schemes over wide range of mobility complexity. In order to parameterize the complexity, we define mobility entropy in CSE. Mobility entropy works as an objective criterion of complexity. Thus, it acts important factor in networks. Small entropy is associated with well-structured mobile environments. A random or chaotic mobility model gives large entropy.

The Potential-based entropy adaptive routing (PEAR), which carries out message routing adaptively over the change of mobility. PEAR dynamically changes message replication on level depending on mobility entropy to always achieve high delivery rate. A node basically transfers messages toward the nodes of higher delivery probability with less message replication at smaller entropy, but it replicates more messages at larger entropy to maintain delivery rate. PEAR is not aware of entropy by itself. Node mobility initiates replication, and this makes PEAR entropy-adaptive.

PEAR inherits the concept of potential-based routing PBR), which is a family of message routing protocols that a node has a scalar value called potential for each destination, forwards messages toward the neighbor that has the lowest potential. The advantage of PBR is that a node can make forwarding decisions without a global knowledge of network topology. PBR only requires neighbor information for this purpose.

The forwarding decisions in PBR are made by potentials over nodes, which we call *potential-field*. We define a recurrence formula for potential-field computa-tion in PEAR, which basically works in autonomously and totally distributed manner. The recurrence formu-lation enables dynamic computation of potential-field without using a global knowledge of network status. It only uses neighbor network status, but constructs global potential-fields appropriately.

We carry out simulations on various CSEs with changing mobility entropy in order that we investigate the effect of mobility entropy on message routing perfor-mance. We recognize that the performance is affected by many environmental features such as network band-width, media-access control (MAC) protocol, message buffer capacity as well as mobility. However, in this work, we assume an ideal environment to demonstrate the relationship between mobility entropy and routing performance.

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2 RELATED WORKS

Traditionally, in order to evaluate the performance of routing in ICMNs, random-based mobility models have been adopted. Such mobility models include random waypoint (RWP), and random walk (RW) and random direction (RD). It has been as recently widely acknowledged that random-based mobility is unrealistic and that routing schemes are frequently discussed on sociologically-organized mobility models, which are studied in the context of buses, taxi, and also in the sociological orbitand pedestrians.

Community-based mobility is also proposed but it is as basically random direction mobility which hierarchically as defined. The problem is that these mobility models possess a particular environmental feature with regard to as mobility entropy; e.g., random-based mobility gives extremely large entropy and sociologically-organized mobility gives smaller entropy.

SOLAR has proposed partially repetitive orbital mobility pattern that a node goes around in a small set of location points, which seems to be better suited to practical scenarios than random-based mobility. A CP corresponds to a community in CSE and node moves in a small set of communities in CSE. In this paper, we add the concept of mobility entropy in the context of CSE.

As for routing in DTNs and ICMNs, several routing schemes have been proposed. Link-state routing scheme was adopted to communication between villages in developing regions. Depending on the methods of computing the link cost, maximum delivery probability (MDP), minimum expected delay (MED) and mini-mum expected dependent delay (MEDD) are proposed. Basically, link-state routing is effective only in the case of well-structured environment. Message path becomes meaningless at a highly dynamic mobile network if used as an enhancement.

Epidemic routing ensures message delivery even in through partitioned networks of highly dynamic topology. But, basically, epidemic routing is flooding-based routing scheme, which copies message to all the nodes encountered, and the copy-received nodes start to copy the message in the same manner. It ideally achieves minimum delivery latency, but, it is said that epidemic routing consumes lots of network resources and buffer space, which results in traffic congestion and to poor performance in realistic scenarios.

Compared to epidemic routing, Spray and Wait improves the overhead of message replication by con-trolling the maximum number of message copy. Mes-sage routing in Spray and Wait is composed of two phases. At first, in spray phase, the message source node makes message copies to neighbor nodes encoun-terd with limitation. Then, it waits until one of the nodes encounters the destination. Controlled replication-based routing like Spray and Wait is useful only in the case of randomly contactable scenarios where random mobility guarantees delivery probability.

In PBR, a node forward messages toward the neighbor that has the lowest potential. Followed by this work, PWave has applied PBR to wireless sensor networks for routing of sensor readings to sink nodes. The concept of using the scenario of Volcano routing scheme (VRS) is also an extention of PBR that computes potential-field to diffuse messages from densely message buffered areas.

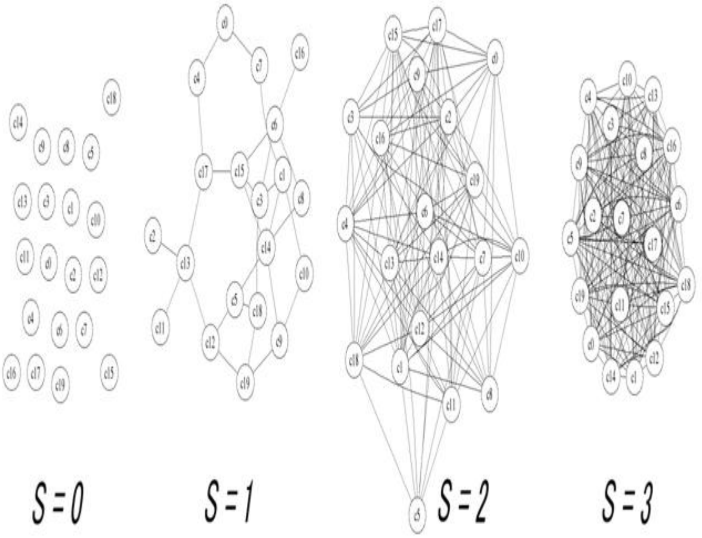

Fig. 1 Communities Organized by Node Traces at Mobility Entropy $S = 0, 1, 2, 3$

Utility-based routing was proposed by in mobile ad hoc networks (MANET) to support disconnected transitive communication. Utility is a scalar value that shows logical proximity to the destination. In that, utility-based routing is the same as potential-based routing in nature. The node of the highest utility will relay mes-sage to its destination with higher probability than any other nodes.

Fig. 2 Nodes Organized by Contacts at Mobility Entropy $S = 0, 1, 2, 3$

3. COMMUNITY STRUCTURED ENVIRONMENT

Let N be a set of nodes in the network, and C a set of communities. A node $n \in N$ belongs to a sub set of C, which we denote by C_n. In the stay mode, a node n stays at one of C_n, which is given by location (n). In the transition mode, n moves from community c_i to community c_j where c_i, $c_j \in C_n$ and $i = j$. A node is in contact with the nodes that stay in the same community. That is,

"Node n and k are within direct transmission range"⇔
"Node n and k are in contact with each other" ⇔

$$\exists c \in C, \text{location}(n) = c \wedge \text{location}(k) = c \qquad (1)$$

Location (n) gives undefined when node n is in tran-sition state.

We define CSE node mobility as follows ($||C_n||$ gives the number of elements in Set C_n),

1. Node n stays at community $c_i \in C_n$.
2. Choose a random value r uniformly in [0, 1).
3. If $p < r$ or $||C_n|| = 1$, goto 1. Parameter p is probability of transition from *stay* mode to *transit* mode.
4. Choose a destination community c_d from $C_n - \{c_i\}$ at the random.
5. Let n move to c_d with transitive time $T(c_i, c_d)$.
6. After n reached the destination, $c_i := c_d$ and goto 1.

We formally define mobility entropy S of CSE as,

$$S = ||N||\ {}_{n}{\sum}_{\in N}{}^{log2}||C_n|| \qquad (2)$$

Here, if every node belongs to the same number of over the communities (i.e., $||C_i|| = ||C_j||$), S can be described as,

$$S = log_2\Omega \qquad (3)$$

Ω is the number of communities that every node belongs to.

We show CSE instances in the case of S = 0, 1, 2, 3 in figure 1 and 2. In figure 1, a community is denoted by a vertex of the graph, and node traces are denoted by the edges. In the figure 2, a node is denote by a vertex of the graph, and a node-to-node contact ability is denoted by an edge. A pair of vertexes that connected by an edge indicates that those nodes are possible to encounter with each other.

As these figures indicate, randomly contactable environment is characterized by larger entropy (e.g., S = 3). Stable or well-structured mobile environments provide small entropy (e.g., S = 0, 1). In fact, random way-point mobility is given by setting $\Omega = ||C||$, which is the case at the largest S.

4 MESSAGE DELIVERY IN PEAR

Here, we focus on message delivery method under the assumption that potential-fields are already given. We discuss autonomous construction of potential-fields in PEAR in the next section.we denote the neighbor nodes (including itself) of node n by *nbr* (n). *nbr* (n) is a set of nodes within the same community of *location*(n) if it is defined(i.e., in stay mode). Otherwise, *nbr* (n) =$\{n\}$.

In potential-based routing, a node has a scalar value that shows a kind of distance to its destination. We call the value *potential* and describe it as $V^d(n)$. When we consider the change of potential over time, we describe it as $V^d(n, t)$, which means the potential for destination d at node n at time t. In this section, we assume that $V^d(n)$ is given and we focus on message delivery on it.

Basically, message delivery in PBR is carried out by forwarding messages toward the node of the lowest potential among its neighbors. After a node forwarded a message to the next node, it usually removes the message from the local buffer. In stable networks (i.e., wired and connected networks), this message delivery scheme is appropriate. However, in DTN scenarios, message delivery should be carried out more redundantly to improve delivery probability and latency.

In DTN environment, we consider that messages should not be just forwarded to the next node; it should be copied but should not be deleted from the local buffer. The copy-source node tries to make another copy of messages again when it encounters to another node. Message replication in this way will improve the delivery probability and latency. When we introduce replication, the network must deal with replica management that involves message deletion after it has reached the destination.

Copy:
The process of making a clone of a message from this node into the other node.

Forward:
The process of making a clone of a message from this node into the other node and deleting the original message.

Replicated messages:
Messages left in the network by the process of copy.

Delete:
The process of eliminating replicated messages from the network.

Thus, in this context, we distinguish the terms of copy, forward, replicated messages and delete.

4.1 SELECTION OF HOP NODES

Let M be a set of messages in the network, and $M^d(\subset M)$ be the messages which destination is d. To deliver a message $m \in M^d$, node n must determine the next hop nodes of m, at first. We define two next hop selection schemes: i.e., best or single candidate selection (BCS) and multiple candidate selection(MCS).

Best (or Single) Candidate Selection (BCS):

$$nexthop^d{}_{BCS}(n) = \{k \mid k \in nbr(n) \wedge F_k{}^d(n) = \max\{F_j{}^d(n)\} > \alpha(4)\}$$

Where, $j \in nbr(n)$ (4)

Here, $F_k{}^d(n)$ is the force that affects on the message m^d from node n toward neighbor k, which we define as

$$F_k{}^d(n) = V^d(n) - V^d(k) \qquad (5)$$

Lower potential of neighbor k enlarge the force from node n to k. In BCS, node n chooses the neighbor k that gives the maximum $F_k{}^d(n)$ as the next hop of M^d at every time unit. Here, the force must be more than a constant value α, the threshold of the least force level. Other-wise, no selection are made for destination d. Nodes encounter and leave as time elapses, and the best can-didate changes according to $nbr(n)$.

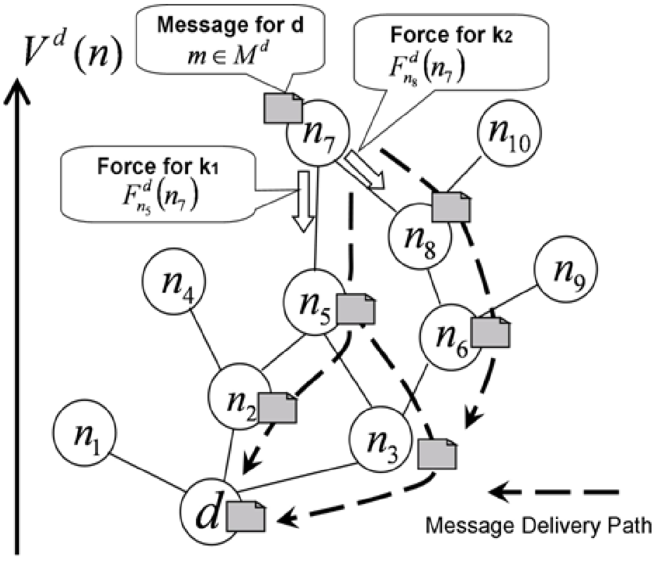

Fig. 3 Message Delivery in PEAR

Multiple Candidate Selection (MCS):

$$nexthop^d{}_{MCS}(n) = \{k \mid k \in nbr(n) \wedge F_k{}^d(n) > \beta\} \quad (6)$$

In MCS, next hop nodes are such neighbors that the force is more than β (> 0). MCS chooses multiple next hop nodes at the same time.

Fig. 3 demonstrates how PEAR delivers on to a message of m ($\in M^d$) to destination d. In this figure, nodes are mapped according to their potential $V^d(n)$ in the verti-cal axis, and the edges show node-to-node contactability (i.e., intermittent connectivity) between nodes. At first, m is possessed by n_7, which has the highest potential in the figure. During n_7 that is not connected to neither of n_5 or n_8, it does nothing. When it encounters both of n_5 and n_8 at the same time, it copies the message to n^5 since $F^d(n^7) > F^d(n^7)$ in BCS, whereas in MCS it copies them to both of n_5 and n_8. In BCS (n_8 does not possess m), after n_5 has left from n_7, n_7 copies m to n_8 since $F_n{}^d{}_8(n_7)$ now provides the strongest force among its neighbors. n_5, n_8 and any other nodes behave in the same way and the message m will be copied to the lower potential nodes until they reach the destination.

At small entropy (e.g., $S = 1$), PEAR only uses a small set of nodes for message delivery, saving resources as much as possible. As entropy S becomes larger, probability of meeting of nodes (e.g., between n_5 and n_7) decreases and message delivery on that paths may fail. However, PEAR maintains delivery probability even in larger S by replicating more messages in the network. At large entropy, n_7 also has links with n_1, n_4 and n_9. Thus, m will be copied to those nodes, which increase the replication level, and achieves high delivery rate.

4.2REPLICA MANAGEMENT

After $nexthop^d(n)$ is determined by BCS or MCS at node n. n tries to copy message $m \in M^d$ to them. Here, some of them may already have a replica of the mes-sage or others may know that the message has already reached the destination. Replica management should be carried out in PEAR in order to reduce the overhead of message duplication and to efficiently use buffer space by removing replicas of delivered message from the net-work.

In PEAR, message m must contain the following in-formation as well as the message body in its header at least.

- MessageID
- Destination
- Time to Live (TTL)

The following information should be managed at ev-ery node locally for each m.

- DisseminationTTL
- IsDelivered

MessageID must be uniquely defined in the network. TTL is a message life time which decreases, for example, every second.

When TTL reaches zero, the message expires (with freeing memory allocated for m including headers). TTL corresponds to the left time for delivery deadline.

DisseminationTTL describes whether node n can send the message to other nodes or not. Initially, node n sets it to TTL of the message when received the message. It decreases in the same manner as TTL does. As we describe later, thus it is the Dissemination TTL changes depending on the process of message replication. If it has expired, node n does not transfer the message to its next hop nodes any longer and deletes the body of it (with free-ing allocated memory space for message body), but continues to check the existence of a delivery certification at the next hop nodes. IsDelivered shows whether de-livery has been certified or not. Originally, when this node receives a message, IsDelivered is set to *false*. After finding the delivery certification, it is set to *true*. The first certificate will be published by the destination node after it has received the message.

4.3 LOOP FREENESS

Loop-freeness in potential-based routing is proved by in the case of static potential-field. Basically, a message which has been forwarded to the lower potential node cannot come again from the upper potential node.

In our modified version of PBR, message delivery is carried out by copying, not by forwarding. Message remains at the nodes where it has infected. Therefore, even in dynamically potential-changing scenarios, messages never loop in PEAR.

5 POTENTIAL FIELD CONSTRUCTION

We described a message delivery scheme in PEAR on a given potential-field. In this section, we describe potential-field construction method in PEAR, which autonomously and dynamically computes the field. Potential computation in PEAR does not require global topology information. It only uses neighbor information but makes an appropriate potential field globally. This is the same property that next hop decision schemes possess.

5.1 RECURRENCE CONSTRUCTION

The potential of node n at the next time step $(t + 1)$ is calculated on the potential of neighbors at current time t. Basically, it inflates by ρ, but the inflation is depressed by the smallest potential among neighbors. This depression is weighted by D, which we call minimum-potential diffusion constant.

All the po-tential value starts at zero. gives a boundary condition that a node must always have zero potential for itself, which means that the potential at the desti-nation must be always set to zero.

The potential at the destination node $V^{d}(d) = 0$ dif-fuses from the message destination around the network with some increase. In this way, nodes farther from the destination gets higher potential, and nodes closer to the destination gets lower potential. Message delivery is carried out from the higher potential node to the lower potential node.

5.2 DYNAMICS

We illustrate how PEAR autonomously constructs a potential-field by Eqn. 7 and achieves message delivery. We assume a quite simple case to make the discussion easy: i.e., four nodes and three communities. Here, n_1 belongs to a community c_1. n_2 belongs to c_1 and c_2. n_3 belongs to c_2 and c_3, and n_4 to c_3. Nodes are in contact with each other only when they are located at the same community; i.e., n_1 and n_2 are in contact when n_2 locates at c_1, n_2 and n_3 are in contact when they stay at c_2, and so on. A contact is denoted by a line, and disconnection is

Initially, nodes have the same potential value at zero. They except $V^{n1}(n_1)$ start to increase by ρ.

(b) As time elapses, $V^{n1}(n_2)$ stays at ${}_{D}^{\rho}$, while $V^{n1}(n_3)$ and $V^{n1}(n_4)$ continues to increase at speed ρ.
(c) The physical topology has changed, and only n_2 and n_3 are in contact. $V^{n1}(n_2)$ starts to increase at speed ρ, while $V^{n1}(n_3)$ decreases toward $V^{n1}(n_2)$. Here, n_3 copies its M^{n1} to n_2.

(d) When the link between n_2 and n_3 is disrupted and instead the link between n_3 and n_4 has set up,
$V^{n1}(n_2)$ and $V^{n1}(n_3)$ increases at speed ρ, while $V^{n1}(n_4)$ decreases toward $V^{n1}(n_3)$. In this situa-tion, n_4 copies its M^{n1} to n_3.

n_2 is now in contact with n_1. $V^{n1}(n_2)$ decreases to ${}_{D}^{\rho}$, and n_2 transfer its M^{n1} to n_1.

6 SIMULATION

We evaluated PEAR, regarding to delivery rate and total message transmissions, on various CSEs by simulation. The purpose of this experiment is to analyze the features of routing schemes in terms of mobility entropy. Thus, we carried out the simulation without being aware of transmission properties (e.g., node-to-node link bandwidth and average message size). In this way, we focused on an ideal case where the effect of them can be ignored.

We set 100 nodes over 50 communities throughout the simulation with changing Ω from 2 to 48: i.e., entropy S from 1 to 5.6. We assumed the case that every node belongs to the same number ($= \Omega$) of communities in each CSE. Throughout the experiment, we set $D = 0.001$ and $\rho = 0.00001$ for potential-field construction (Eqn. 10), and $\alpha = 0.8$ and $\beta = 0.8$ for next hop selection (Eqn. 4 and Eqn. 6). The message lifetime was set to 20000.

We carried out the simulation of node mobility, po-tential field construction and message delivery during the time interval $[-50000, 20000]$. While $t \in [-50000, 0)$, no messages were submitted into the network; only the movement of nodes and potential-field construction were simulated. At *t* = 0, every node sent messages to all the nodes in the network. While $t \in (0, 20000]$, message delivery was also simulated as well as the node movement and potential-field construction.

We evaluated PEAR with other routing schemes such as epidemic routing], Spray and Wait (2-hop scheme) , Minimum Expected Delay(MED) and Maximum Delivery Probability(MDP). In the comparison with these schemes we have prepared completely the same set of CSEs.

6.1 DELIVERY RATE

Link-state routing (i.e., MED and MDP) achieved about 95% message delivery at *S* = 1, but it failed 50% at larger entropy. Spray and Wait delivered only 28% of messages at *S* = 1, whereas it delivered about 95% at larger entropy. PEAR achieved more than 95% delivery rate over any entropy environments, which is almost the same level that Epidemic routing did. These results indicate that PEAR has dynamically adapted to any given environments whether they are highly-dynamic or relatively well-organized. However, link-state routing and Spray and Wait have achieved good performance at the specific situations.

The latency of message delivery in MED and MDP gets large sharply as *S* increases, resulting in unsuccessful message delivery at time 20000. As for other routing schemes, Epidemic routing totally performed a good performance with regard to delivery rate, and Spray and Wait stopped the increase of message delivery rate at 28% around time 5000 at *S* = 1, but the rate sharply increased at *S* = 3, 5.

From these results, we summarize that PEAR is useful for wider mobility entropy scenarios than the other routing schemes except Epidemic routing. Link-state routing (i.e., MED and MDP) is just useful at quite small entropy. Spray and Wait routing is useful for larger entropy scenarios, where nodes are possible to directly contact with most of the nodes in the network.

6.2 TOTAL MESSAGE TRANSMISSIONS

A total message transmission is the total count of ap-plication message exchange among nodes. Figure 8 shows the relationship between total message transmissions and entropy. PEAR (BCS) reduced the transmissions to about 11% (at *S* = 1) and 23% (at *S* = 5) of Epidemic routing. Link-state routing (i.e., MED and MDP) transmitted about 3.5% of Epidemic routing at *S* = 1, where they achieved high delivery rate. Spray and Wait transmitted about 12% at *S* = 5. PEAR generated two or three times more transmissions than link-state routing and Spray and Wait.

Figure 4 shows total message transmissions over the time interval from *t* = 0 to *t* = 20000. These graphs show the summary of transmission: e.g., 1000 transmissions at time 3000 means that 1000 messages have been exchanged in the network during [0, 3000]. From the re-sults we read that message delivery in Spray and Wait was carried out mostly during [0, 5000] at any CSEs. This is the same feature of Epidemic routing. Another thing we read from the results is that link-state routing and PEAR carried out the delivery process gradually at *S* = 3, 5 though it has finished around *t* = 5000 at *S* = 1.

Finally, on careful manipulation, we get the correct rule that matches the packet with lowest number of active rules in hand, with a space complexity of O (n) and time complexity of O(log n) thereby, reducing the number of corrupted packets occurring in the network

7 CONCLUSION

We proposed community-structured environment (CSE) and potential-based entropy adaptive routing (PEAR) in this paper. CSE has enabled the classification of mobile environments in terms of mobility entropy. In CSE, stable or well-structured mobile environments are characterized by small entropy. Randomly contactable environments are characterized by large entropy.

Using CSE, we have analyzed the features of routing schemes by simulation. In our experiment, link-state routing (e.g., MED and MDP) has worked well at small entropy environments such as *S* = 1 but failed to 50% delivery at larger entropy. Spray and Wait has achieved good performance at larger entropy, but only 28% messages have been delivered at *S* = 1.

PEAR has achieved more than 95% message deliv-ery over any mobility entropy environments by adap-tively changing the message delivery form. At small entropy, PEAR has aggressively transferred a message in hop-by-hop manner using the appropriately developed potential-fields. At large entropy, PEAR has au-tomatically shifted to let mobility deliver the message with making more replicas in the network. In this way, PEAR has maintained the delivery rate.

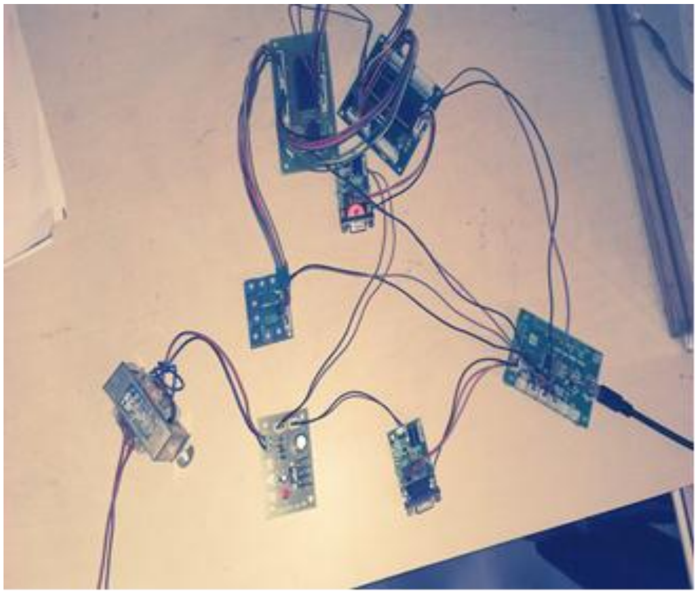

Fig. 4 Light,Temperature and Humidity Sensors.

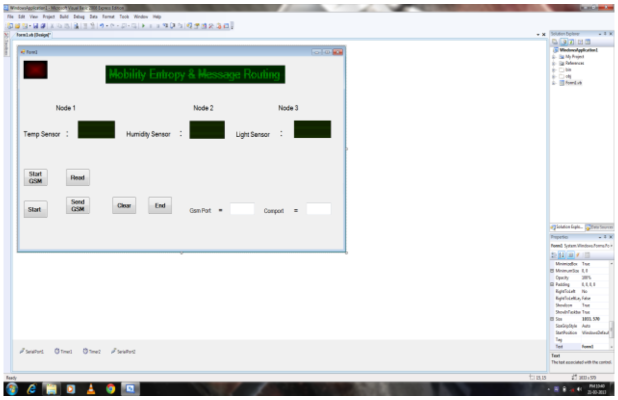

Fig. 5 Light,Temperature and Humidity Values.

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REFERENCES

[1] A. Balasubramanian, B. N. Levine, and A.Venkataramani. DTN routing as a resource allocation problem. In *ACM SIGCOMM*, 2007.

[2] A. Basu, A. Lin, and S. Ramanathan. Routing using potentials: A dynamic traffic-aware routing algorithm. In *ACM SIGCOMM 2003*, 2003.

[3] J. Ghosh, H. Q. Ngo, and C. Qiao. Mobility profile based routing within intermittently connected mobile ad hoc networks (ICMAN). In *ACM IWCMC*, 2006.

[4] J. Ghosh, S. J. Philip, and C. Qiao. Sociological orbit aware location approximation and routing (SOLAR) in MANET. *ACM Ad Hoc Networks*, 5(2):189–209, Mar 2007.

[5] Z. Haas, J. Y. Halpern, and L. Li. Gossip-based ad hoc routing. In *IEEE INFOCOM*, 2002.

[6] J. Hahner, C. Becker, and K. Rothermel. A protocol for data dissemination in frequently partitioned mobile ad hoc networks. In *IEEE ISCC*, 2003.

[7] X. Chen and A. L. Murphy. Enabling disconnected transitive communication in mobile ad hoc networks. In *ACM POMC*, 2001.