Dynamic Rendezvous based Routing Algorithm on Sparse Opportunistic Network Environment

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***Abstract*—Opportunistic network is a challenge network where the nodes need to communicate with each other even either direct or indirect routes between them may not permanently exist due to the nodes' random movement. Most routing algorithms in this dynamic network environment employ *store-carry-forward* paradigm by which a node can keep the receiving messages, carrying the messages with them when moving and then forwarding the messages (or the copies) to the opportunistic meeting nodes when possible. This routing model works well in the networks with high-to-moderate node density in which the opportunity that the moving nodes can meet with each other is rather high. On the other hand, it has been reported that the delivery ratio becomes remarkably low in the sparse network environment especially when there is strict constraint on message delivery deadline. In this paper, we introduce the novel concept of rendezvous place where the passing nodes can announce, deposit or pickup their own messages without having to meet the other nodes carrying the desired message. In the proposed scheme, the rendezvous place can be detected automatically and its area's size and shape are dynamically changed according to the interaction among nodes passing around the area. The results from intensive simulations show that our proposed routing algorithm can achieve higher delivery ratio and utilize lower energy consumption than traditional opportunistic routing algorithms especially in sparse network environment.**

I. Introduction

Opportunistic Network (OppNet) is an extreme type of Delay Tolerant Networks (DTNs) where the source and destination nodes might never be fully connected at the same time, thus there is no guarantee on the existence of a complete path between two nodes wishing to communicate [1]. This intermittent connections may result from several factors such as high node mobility, low node density, environmental interference and obstruction, short radio range and malicious attacks [2] etc. The node movement in OppNet is extremely random in some networking environment, thus the probability of message delivery from source to destination is difficult to assure. Example of such networks are sparse mobile ad hoc network [3], military tactical networks [4], [5] or sensor networks, such as ZebraNet [6], SWIM [7] which are wireless sensor networks in which nodes move throughout an environment working to gather and process information about their surroundings. Commonly, the key differentiating factors among those scenarios are the amount of predictability and control over the contacts between the message carriers [8]. A key concept behind Opportunistic Routing (OR) is overhearing and cooperation among relaying nodes to overcome the drawback of unreliable wireless transmission [9]. Since the mobile nodes are not always connected to each other, the forwarding algorithms in such network commonly follow a store-carry-forward (SCF) paradigm. This SCF employs storage space and node mobility to overcome the intermittent connectivity [10]. The messages sent from the source node are carried by intermediate nodes to other geographical area and transfered to adjacent nodes until the destination node receives this message. Since this fundamental SCF routing model realistically requires a certain sufficient occasion of *direct* encounter among moving nodes to exchange messages, its routing performance will highly degrade in the low-node-density sparse network [11]. Although there are several existing OppNet routing solutions [5], [12]–[16] proposed in the literature, very few proposals address the problem in this sparse network environment especially when the OppNet nodes are energy-constrained [17], [18] and the direction of their movement cannot be controlled. One interesting application of such OppNet environment is the sensor OppNet for wildlife monitoring and tracking [6], [7].

In this paper, we proposed a novel Dynamic Rendezvous based Routing Algorithms (DRRA) to increase message exchanging opportunity even in the sparse network environment. We utilize the fact that there should be some node-gathering (Rendezvous) places forming somewhere at some specific time in the real network. These Rendezvous places may be either predictable such as along the river in the wildlife monitoring application, or non-predictable such as disaster and emergency networks. An energy constrained node should maximize its resource usage to communicate with the others only when entering into the rendezvous area. In the proposed scheme, the rendezvous place is dynamically marked by the help of a special controllable Rendezvous node and the proposed rumor protocol to let nodes in the rendezvous area exchange messages more efficiently without having to directly meet with the other nodes.

The rest of the paper is organized as follows. In section II, we discuss the overview of SFC routing models and existing works. The detail of rendezvous based routing model is elaborated in section III. In section IV, we present the result of our simulation and show the performance of our scheme

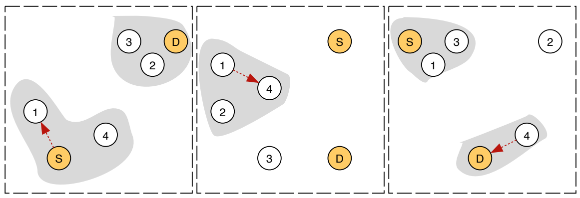

Fig. 1. Store Carry and Forward routing model

under different conditions. We conclude the paper and point out some future research directions in section V.

II. The SCF routing models and existing works

In OppNet, the messages are delivered using Store-Carry-Forward routing by which the nodes can exchange data whenever they come in close. If there is no direct connection from source to destination, data holding nodes will discover their nearest neighbor nodes to forward messages toward the destination node as shown in Fig. 1. There are several existing works in the literature [5], [16], [19]–[23] with the aim for 100% delivery ratio which is quite difficult to achieve especially in sparse network with constraints in energy consumption and message delivery deadline.

Vahdat et al [16] proposed the epidemic routing using uncontrolled flooding algorithm in which the replication of source data is not restricted with any limits in order to route the message from source to destination in the intermittently connected network. However, this type of routing incurs significant demand on both bandwidth and buffer. To address the excess traffic overhead, Khaled et al [19] proposed a Controlled Flooding scheme which can limit the flooding by three parameters: Willingness probability, Time-to-Live, and Kill Time. Nevertheless, flooding based routing performance degrading has been reported in a very sparse network [20].

Lindgren et al [21] proposed a prediction based routing called PROPHET (Probabilistic Routing Protocol using History of Encounters and Transitivity) by estimating the delivery predictability to indicate the probability of success in delivering a message to the destination from the local node. In this prediction based routing category, Brun et al [22] also proposed a protocol utilizing the motion vector of mobile nodes to predict the future location of mobile nodes by using the knowledge of relative velocities of a node and its neighbor nodes to predict the closest distance between two nodes. Although the prediction based approach can reduce traffic overhead in the network, but it lacks of the aim to improve the performance in extremely low node density and failed in some certain cases which leads to the delivery ratio reduction.

To refine the prediction based routing, Boldrini et al [23] proposed the History based routing (HiBOp) which exploits current context information for data forwarding decisions. Even though, this context based routing approach can reduce the resource consumption in terms of network traffic and storage but it increases the delay which results in significantly less efficient than Epidemic algorithm. Kerdsri et al [5] proposed DORSI protocol with the concept of content based routing which aims to classify the data in the network by messages' significance level in order to guarantee the delivery of more important data. However, the decreasing in network performance under sparse environment is not mentioned in this proposed protocol. Overall, the performance of most existing algorithms are degrading in very sparse node density and the energy consumption does not take in to the consideration which is a crucial factor in such mobile sensor devices such as in wildlife monitoring.

III. The proposed Rendezvous based OppNet system

A. System model

The proposed system is designed to efficiently use the node-gathering area, i.e. Rendezvous place, for depositing the delivered messages as much as possible so that the messages can be picked up by the destination node without requiring the exact timing of direct contact between the node carrying a message and the desired destination node. In addition, all nodes should reserve its energy as much as possible when they are out of the Rendezvous area.

As shown in Fig. 2, the OppNet node, N_c, whose movement direction is uncontrollable, moves in the system using *Power Saving Mode* until it reaches the Rendezvous place where it will turn itself to *Full Power Mode* in order to announce its arrival, deposit its carried messages and pick up the messages destined to itself, to/from the Rendezvous place. The Rendezvous Rumor protocol and Rendezvous Node Sweeping mechanism are used inside the Rendezvous area to let messages being exchanged more effectively without the need of direct contact between the OppNet node and the high-resource direction-controllable Rendezvous node, N_{rv}, which is act as the center of the Rendezvous place. The Rendezvous nodes will move around the OppNet network to create suitable Rendezvous places according to the proposed *Rendezvous Place Searching algorithm*.

B. OppNet node's operational modes: "Full Power" and "Power Saving"

The OppNet node (N_c) is a mobile node equipped with the radio interface whose transmission rage is adjustable in range of $[r_c^{min}, r_c^{max}]$. The node will operate in either *Full Power mode* or *Power Saving mode* according to its location.

1) Full power mode: In this mode, the node will use its full transmission power, r_c^{max}, to search for nearby nodes and exchange messages. It will switch to this mode only when getting into the Rendezvous area.

2) Power saving mode: The node, by default, operates in this mode if it is outside the Rendezvous place. In this mode, it will alternately change its transmission range between r_c^{min} and r_c^{max} in the process of searching for nearby nodes. However, if it receives the searching signal from the other node, it will switch to its full r_c^{max} immediately in order to increase opportunity to exchange messages with the encountered node

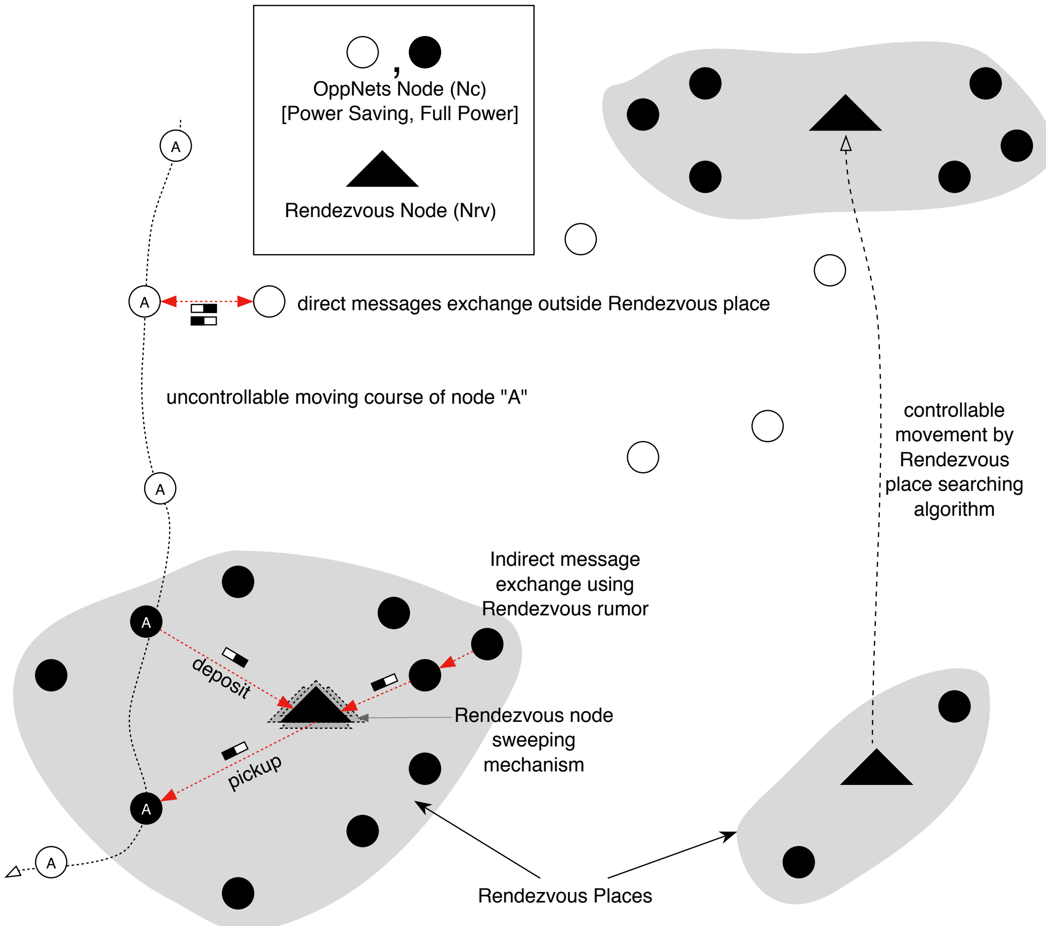

Fig. 2. System model

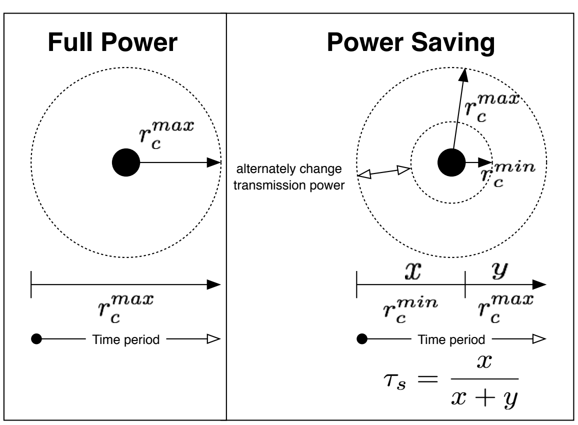

Fig. 3. Operational modes

as much as possible. Then, it will switch back to minimum r_c^{min} when departing from the communicating node. Besides the r_c^{min} and r_c^{max} values, the ratio of the time interval being in it full r_c^{max} over the whole time period is a configurable parameter,τ_s , as shown in Fig. 3.

C. Rendezvous place and its Rumor protocol

The Rendezvous place is a dynamic area centered by a special controllable Rendezvous node, N_{rv}. This N_{rv} node is full of resources such as large message storage and high radio power with maximum transmission range R_{rv}. The Rendezvous place is controlled by the Rendezvous node using Rendezvous rumor protocol.

The area in Rendezvous place is not fixed as the maximum radio range, R_{rv}, of the Rendezvous node, instead it is virtually determined by the covering radio range of the most outer OppNet nodes which can relay the data messages from the Rendezvous node, as shown in Fig. 2

When an OppNet node detects the *Rendezvous Area rumor message* (RA) broadcasted from the Rendezvous node, it learns that it enters to the Rendezvous area. Then, it will switch its operational mode to *Full Power mode* and try to rebroadcast such *Rendezvous Area* rumor message so that the other reachable nearby nodes can learn about Rendezvous place and can adaptively expand the area on-demand. Additionally, the OppNet node in the Rendezvous area will periodically announce its arrival and upload its carried data messages to the Rendezvous node via the *Keep-Alive* rumor message (KA) and the *Deposit* rumor message (DP) respectively. Note that

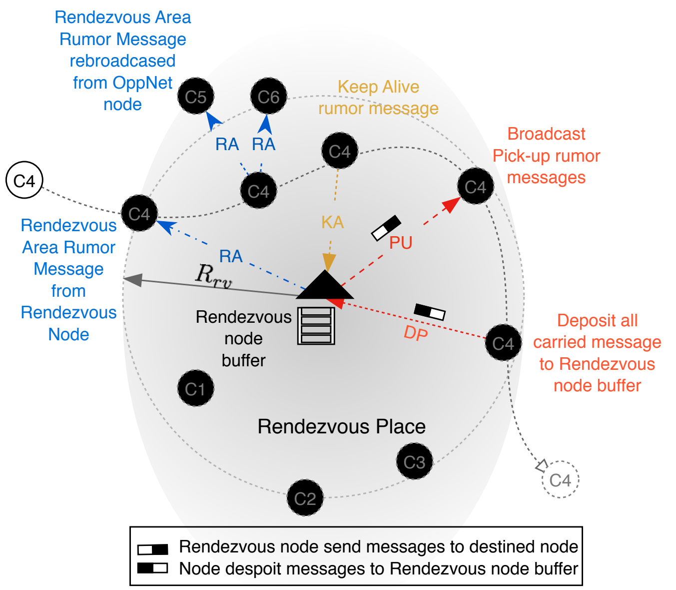

Fig. 4. Rendezvous Place

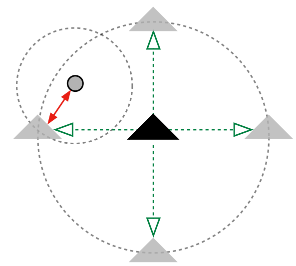

Fig. 5. Sweep mechanism

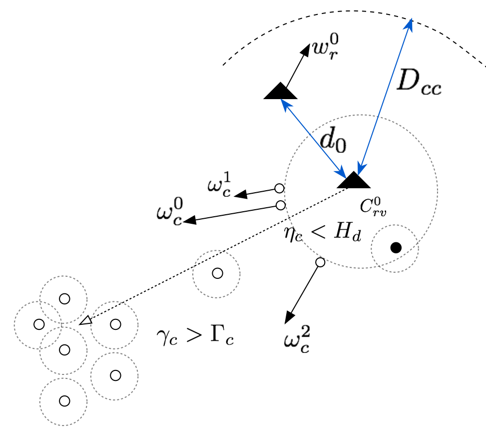

Fig. 6. Rendezvous place searching

all types of rumor messages will be automatically repeated with *duplication filtering* function throughout the area by other OppNet nodes.

Once the rendezvous node receives the *Keep-alive* rumor message which contains the sending node ID, it will gather all data messages destined to the node ID from its message storage, encapsulate those found messages into the created *Pick-up* rumor message and then broadcast the *Pick-up* message (PU) throughout the Rendezvous area. On the other hand, the Rendezvous node will keep all of data messages contained in the received *Deposit* rumor messages in its storage for later sending out to the area when the target node appears later as seen in Fig. 4.

In addition to the Rendezvous rumor protocol, the Rendezvous node implements the rumor message sweeping algorithm in order to increase the chance to collect as many rumor messages as possible. Instead of always being stationary at the center location of the Rendezvous place, the rendezvous node will periodically move to its four directions (North, East, West, South) by the distance of its radio transmission range as shown in Fig. 5. This design lets the OppNet nodes on the edge of Rendezvous node's radio range, whose radio signal may not reach to the Rendezvous node due to the difference in their radio transmission range, can speak back to the Rendezvous node.

D. Rendezvous place searching algorithm

In the proposed system, the Rendezvous node should move to find the node-gathering area corresponding with the real behavior of OppNet node.

1) Predictable behavior OppNet nodes: In some applications, the movement of OppNet node is somehow predictable. Take a wildlife monitoring as an example, most animals are usually cyclically gathering in the high supplies area such as along side of the main river of some specific place at some specific time [24]. In these applications, the Rendezvous nodes can be programmed to be located at those areas at the proper time in order to maximize the effectiveness of the proposed system.

2) Non-Predictable behavior OppNet nodes: Without any priori knowledge about OppNet node, the proposed *dynamic Rendezvous Place Searching Algorithm* can be used to guide the Rendezvous nodes to the node-gathering area. The Rendezvous node will decide to move to the new node gathering location if the number of OppNet node in the current Rendezvous place (η_c) falls below the predefined departure node threshold, H_d. The movement direction, $\vec{\Delta}$, will be determined periodically based on the collected statistical data from both previously contacting OppNet nodes and other neighboring Rendezvous nodes as in Eq.1. In the equation, $\vec{w_c}$ is the departure directional unit vector of the contacted OppNet nodes, $\vec{w_r}$ is the directional unit vector of the other Rendezvous nodes and the φ is a configurable weighting factor between group of OppNet nodes and group of other Rendezvous nodes in the area.

$$\vec{\Delta} = \sum_{i=1}^{C} \vec{\omega_c^i} + \varphi \sum_{j=1}^{R} \delta\left(d_j\right) \vec{w_{rv}^j} \tag{1}$$

While the $\delta\left(d_j\right)$ is the on-off function to include only the other Rendezvous nodes whose distance d_j is the range of cutoff distance perimeter, D_{cc}, and the C and R are the number of contacted OppNet nodes and the number of other Rendezvous nodes respectively.

$$\delta(d_j) = \begin{cases} 1 & ; \quad d_j \quad \leq \quad D_{cc} \\ 0 & ; \quad d_j \quad > \quad D_{cc} \end{cases}$$

The Rendezvous node will decide to stop at the expected node-gathering area when the number of OppNet nodes in the current Rendezvous place (γ_c) become greater than the predefined Rendezvous place node threshold, Γ_c as shown in Fig. 6.

IV. Evaluation

The objective of the evaluations is to analyze the performance of our proposed protocol on the sparse network environment comparing with traditional OppNet protocols. We compare both predictable and non-predictable behavior OppNet nodes with the commonly well-known Epidemic protocol [16] under different node density environments.

A. Simulation setup

We setup a simulation environment using ONE (Opportunistic Network Environment) [25], which is a powerful tool designed for running opportunistic network simulation with various routing protocols and different movement models. All the results are obtained by averaging over a few hundreds independent simulation runs with different seeds. For the OppNet simulation model, the main parameter that largely effected the evaluation performance is the movement model. In our evaluation, we deploy Group movement model instead of the most commonly used, Random Way Point (RWP) model [26], to correctly capture the the actual behavior of node movements. In fact, several multi-hop wireless network scenarios are most realistically represented using Group movement model [27] which represents the random motion of a group of mobile nodes as well as the random motion of each individual mobile node within the group. This is the vital case for modeling the routing simulation in OppNet since the movements in several cases are in swarm behavior, in which nodes are aggregates together and moving in some directions, such as the movement of animals or military tactical operations. The other parameters that mainly effect the evaluation performance are the area of operation, the wireless range of the nodes, node velocity and spatial location of the nodes [26]. In our simulation, we fix the number of nodes while increasing and decreasing the area of operation which results in wide range of node density parameter for evaluation. Node density (λ) is defined as the number of nodes per unit area. If N nodes are distributed in a square grid of size $M \times M \quad m^2$ then the λ is given by $\lambda = \frac{N}{M^2}$. The wireless range of our OppNet node can be adjusted depending on the environment while the node velocity is equal to the normal human walking speed. The common parameters are summarized in Table I.

TABLE I
SIMULATION VARIABLES

Parameters	N_c	N_{rv}
Message Size	500 KB - 1 MB	
Maximum Radio Range	30 Meters	100 Meters
Transmission Speed	54 Mbps	
Router	DRRA — Epidemic	
Moving Speed	0.5 - 1.5 m/s	
Movement Model	Group Movement Model	

B. Metric

Opportunistic routing protocols are commonly evaluated by delivery ratio, median latency and network overhead. In this paper, we focus on delivery ratio and network overhead in term of energy consumed to deliver a message within a specific message deadline. We assume that all messages delivered within the deadline has no difference in protocol performance.

a) Delivery ratio (D_r): is defined as the ratio of the total number of messages successfully delivered within the deadline ($M_{delivered}$) to the total number of messages created from the source nodes that need to be delivered ($M_{created}$) as shown in Eq. 2.

$$D_r = \frac{M_{delivered}}{M_{created}} \tag{2}$$

b) Energy consumption (E_c): is defined as the amount of energy consumption required by all related OppNet nodes to deliver one messages. We simplify the energy consumption model by only considering for the communication energy consumption of the wireless interface to transmit a message by determining the number of all necessary protocol packets, M_{packet} per number of $M_{created}$ messages. To transmit an L bit-length packet using radio interface with transmission length, d, the consumed energy, E_T, can be determined by Eq.3 [28], [29], where α is the power loss component with $\alpha \in [2, 4]$ and $\epsilon f_s \left[J/(bit/m^{\alpha})\right]$ is the amount of energy consumed by an amplifier to transmit one bit data at an acceptable quality level.

$$E_T \quad = \quad L \cdot \epsilon_{fs} \cdot d^{\alpha} \tag{3}$$

As a result, all energy consumption (E_c) can be derived as Eq. 4

$$E_c \quad = \quad \frac{M_{packet}}{M_{created}} \cdot L_p \cdot \epsilon_{fs} \cdot r^2 \tag{4}$$

Note that L_p is the size of protocol packet, r is the radio transmission range of the protocol and α is equal to two in our simulations.

c) Protocol performance (P_{Ψ}): is a composite metric to capture the gain in both delivery capability and energy saving capability of a specific protocol, compared with the baseline protocol, Epidemic. The P_{Ψ} can be calculated from Eq. 5.

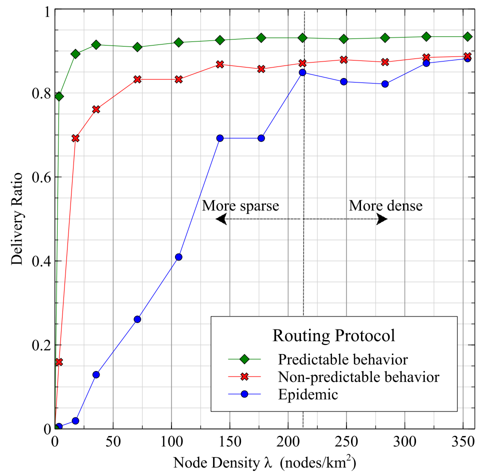

Fig. 7. Delivery Ratio per Node Density

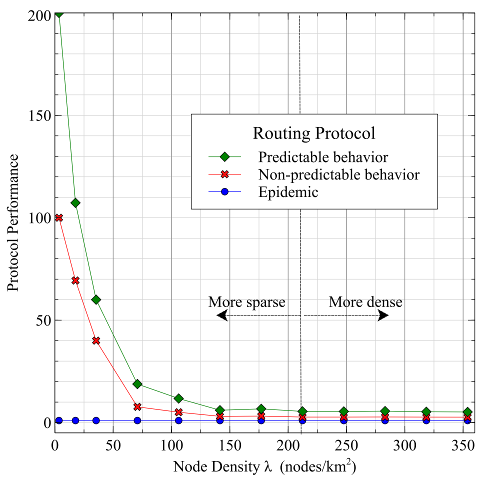

Fig. 8. Protocol Performance per Node Density

$$P_\Psi = D_r^{P,B} \cdot \frac{1}{E_c^{P,B}} = \frac{D_r^P}{D_r^B} \cdot \frac{E_c^B}{E_c^P} \qquad (5)$$

In this Equation, P is the target protocol while B is the baseline protocol (Epidemic protocol, for example) to be used as comparative energy reference.

C. Simulation Results

This section shows the results of the different simulations that have been performed evaluating the impact in the performance. The following subsections include the results of each set of simulations.

1) Protocol performance: Firstly, the comparison of delivery ratio is shown in Fig. 7, where $x - axis$ represents the node density (the number of nodes in the area of one km^2) and $y - axis$ shows the delivery ratio. In our simulation, we assume the environment of one Rendezvous node and the ratio of time interval between full power and power saving, τ_s of 0.5. Fig. 7 shows that our proposed protocols gain slightly

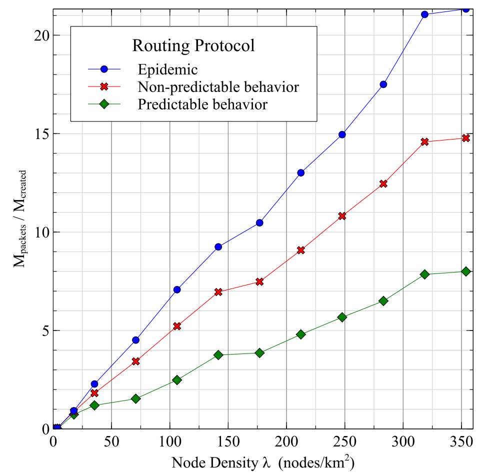

Fig. 9. Number of Generated Protocol Packets per Created Messages on Node Density

better delivery ratio in the dense environment. On the other hand, the proposed protocols gain significantly higher delivery ratio in the sparse environment by maintaining the ratio up to 80%, even when node density is as low as 50 $nodes/km^2$ in non-predictable behavior or as low as 5 $nodes/km^2$ nodes in predictable behavior. Over all in average, our proposed protocols gain approximately 40% higher delivery ratio than existing traditional Epidemic routing.

The reason behind the behaviors from this result is that the Rendezvous concept can be clearly performed better when the node density becomes sparse since all nodes can effortlessly exchange messages in the dense network. However, in the sparse network, the Rendezvous nodes can help facilitating the messages exchange mechanism among OppNet nodes which resulting in much higher delivery ratio. In addition, with the knowledge of node gathering-area, the delivery ratio can be further increased especially in the extremely low node density.

Furthermore, the proposed protocols utilize less energy consumption which is a vital factor in opportunistic network because the mobile nodes in this scheme are usually equipped with limited power resources that the performance can be seen in Fig. 8. Similar to graph of delivery ratio, we compare the protocol performance ($y-axis$) on node density ($x-axis$), in which the P_Ψ can be calculated from Eq. 5. It can be obviously seen that the proposed protocols in Fig. 8 gain significant high protocol performance with the node density below 100 nodes/km^2. Therefore, our protocol can gain higher delivery ratio while minimizing the energy consumption especially in the extreme sparse environment. Fig. 9 shows the number of protocol packets, M_{packet} per $M_{created}$ which represent the amount of packet generated for sending 1 message. The graph shows that the our proposed protocols generate less $M_{packet}/M_{created}$ than Epidemic counterpart. Additionally, Fig. 10 shows the comparison of energy consumption in term of $L_p \cdot \epsilon_{fs}$ which suggests that our proposed protocol utilize less energy than traditional Epidemic protocol.

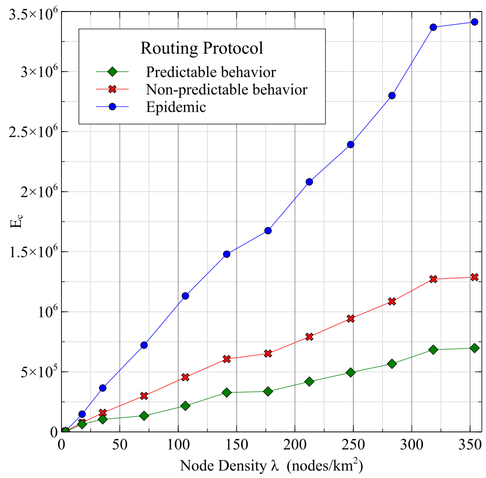

Fig. 10. Energy Consumption per Node Density

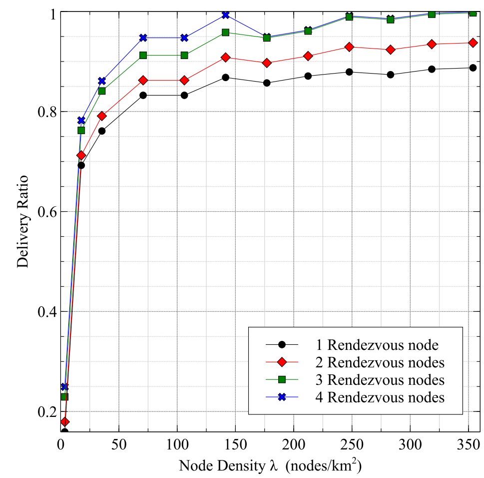

Fig. 12. Multiple Rendezvous Nodes

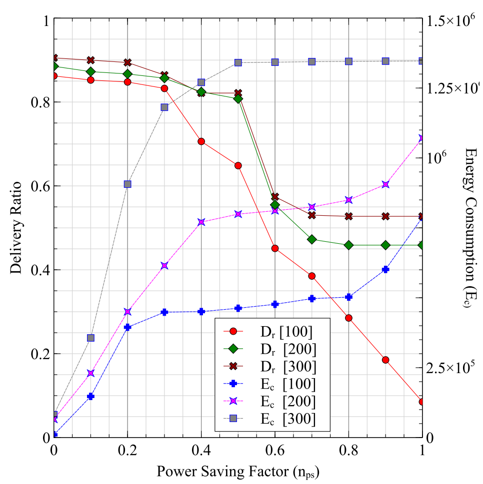

Fig. 11. The Optimum between Delivery Ratio and protocol Performance

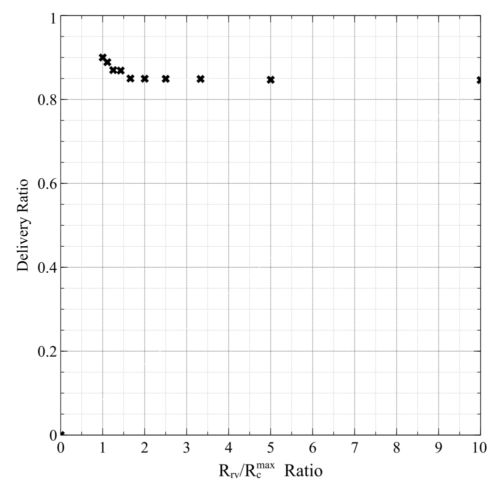

Fig. 13. R_{rv}/R_c^{max} ratio

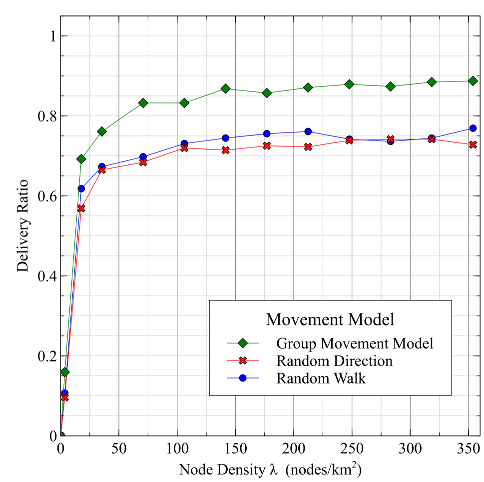

Fig. 14. Movement Model Comparison

2) Power saving factor: In this section, we study the factors effecting the power saving and the trade-off between power consumption and delivery ratio. We define the Power Saving Factor, n_{ps} as the energy consumption parameter to analyze the power utilization of our proposed protocol which can be determined as in Eq. 6. In the simulation, we select the density of 100, 200 and 300 nodes to study the impact of power saving factor to the delivery ratio on different density environment.

$$n_{ps} = \tau_s \cdot \frac{r_c^{max} - r_c^{min}}{r_c^{max}} \tag{6}$$

Fig. 11 shows the delivery ratio and energy consumption on power saving factor. The higher n_{ps} presents less power utilization which can see that the delivery ratio declines with the power saving factor. This means the attempt to save the energy can reduce the delivery ratio. However, on the right $y-axis$ of energy consumption can show that the higher power saving factor results in lower energy consumption. From this graph, the higher density of nodes illustrates in the higher delivery ratio and energy consumption.

3) Rendezvous node factor: We investigate the main parameters effecting the environment of N_{rv} in this part. In Fig. 12, the number of N_{rv} are varied from one to four nodes in our simulation. The result shows similar trend of overall delivery ratio which slightly declining when the node density decreases. Nevertheless, the delivery ratio increase when more rendezvous nodes are injected into the environment. The results suggest that more number of rendezvous node can gain higher delivery ratio. Fig. 13 shows the relationship between R_c^{max} and R_{rv} over the delivery ratio, starting from R_c^{max}/R_{rv} ratio of 0.1 to 1.0. This graph shows moderate incrementing in delivery ratio when the ratio of R_c^{max}/R_{rv} increases. The result suggests that the value of R_c^{max} has slightly effect on delivery ratio.

Lastly, the graph from Fig. 14 shows that our protocol can perform higher delivery ratio when the movement model is in the group. However, when the movement of nodes are total random, the delivery ratio decreases. This is the result from our protocol that can work well when node are forming the group but not in the individual form of moving.

V. Conclusion

Opportunistic Routing techniques can be applied in plentiful variety of scenarios such as military network or wildlife monitoring. In this paper, we investigate the use of rendezvous points in opportunistic network routing to increase the delivery ratio in extreme sparse network environment. This novel protocol proposes the two new types of node, Rendezvous node and OppNet node, which can help maintaining the messages in one place as long as possible in order to bridge the gap of time and space domain. In this Rendezvous place, the passing nodes can announce, deposit and pickup their own messages without meeting with other nodes that carried desired messages. The size and shape of Rendezvous place can be adapted to the environment of OppNet nodes in the area. We define our routing model in two functions: predictable and non-predictable behavior OppNet node functions. The result suggest that our protocols perform significant higher in protocol performance which is the trade off of delivery ratio per energy consumption. We can simply imply that if the location of rendezvous place can be predicted, we can achieve highest network performance. In the future work, this concept of smart node can be further extend to increase the intelligence of the node since the technologies are advanced rapidly.

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