Game-based Data-Forward Decision Mechanism for Opportunistic Networks

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***Abstract*—The appearance of plenty of intelligent devices equipped for short-distance wireless communications boosts the fast development of Opportunistic Networks application. As a special application, the Opportunistic Networks select the 'Store-Carry-Forward' routing pattern, instead of the usual hop-by-hop transmission mode. Aiming at the problem of forward-decision of the routing pattern, this paper introduces a new way based on game-theory with context of nodes. By selecting of four important context parameters and combined with Kalman Filter, the mechanism conducts the way of two-player games to do the decision of data-forward between two nodes. By this mechanism, the receiver node involves in the decision process and optimizes the performance and loads of it. The simulation results have shown that this mechanism enjoys superiority in delivery ratio and total consumption among forwarding.**

***Index Terms*—Opportunistic Networks; MANET; Game Theory**

I. INTRODUCTION

The appearance of plenty of intelligent devices equipped for short-distance wireless communications and the rapid growth of mobile Ad Hoc Network boost the fast development of Opportunistic Networks application. At the same time, it prompts new problems and challenges.

A mobile ad hoc network (MANET for short)[1] is a self-configuring network of mobile devices connected by wireless links. Each device in a MANET is free to move independently in any direction, and will therefore change its links to other devices frequently. Each must forward traffic unrelated to its own use, as well as a router. In usual router mechanism of MANET, the network is considered as connected in most of time, and each couple nodes have at least one path between each other. So, many MANETs router algorithms, such as AODV (Ad-hoc On-Demand Distance Vector)[2] or DSR (Dynamic Source Routing)[3], build the router path in them. All data-transmissions and services are based on such router algorithms in MANETs.

Recently, some MANETs are found that they cannot be fully connected because of the factors of device-shift, network-sparse and signal-attenuation. Also such factors make the MANET become some Ad Hoc sub-networks, which are partial-connected, separated from each other and Topology-changed dynamically. And the mobile devices in different sub-networks can’t associate. In these cases, the common router algorithms can’t work well and a special router mechanism is needed. The research of ‘Opportunistic Network’[4] is aimed at the new implementation region.

The Opportunistic Network takes full advantage of the communication opportunity in the movement of the mobile devices. It adopts the model of ‘Store-Carry-Forward’ to transmit the data and is not essential to link with the full-connected of the network. Figure I is a demo of the Opportunistic Network. As the figure shown, the source node is S and the target node is D. At the time of t1, S sends the data to Node 3. But Node 3 is not connected with any nodes of D’s neighbor. So the Node 3 stores the data and carries it while it moves. At the time of t2, the Node3 can communicate with Node 4, and it find the Node 4 have more chance to become the D’s neighbor. So the Node 3 transmits the data to Node 4. And the Node 4 sends the data to D at the t3.

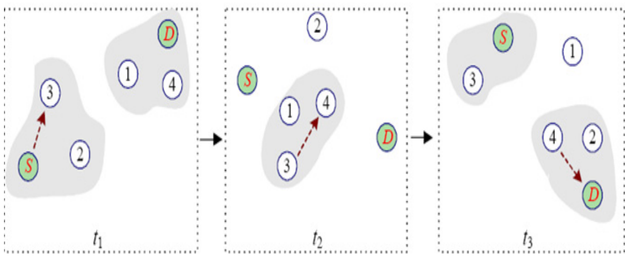

Figure1. Demo of Opportunistic Network

As a special mode of MANET, the Opportunistic Network promotes a lot of applications of MANETs. For example, the smart mobile devices are equipped with the

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vehicles which formed an Opportunistic Network to realize the traffic incident pre-alarm and other road security applications [5]. Many hand-hold electric devices, such as MP3 player, mobile telephones and PDA, can communicate each other by Bluetooth or Wi-Fi, so they can build up an Opportunistic Network to share data or visit Internet [6]. And another example of Opportunistic Network is used to collect information of wild animals in the nature by wireless sensors [7].

In the implementation of Opportunistic Network, the transmitted data seldom can be transmitted from source node to target node directly. And most of them must go forward through many forwarding-nodes. How to select the efficient forwarding-nodes and finish the transmission job successfully is a vital research field in Opportunistic Network. And the researchers provide many ways. Each of them has its own advantages and disadvantages.

The paper is focus on improving the Qos of the forwarding-nodes by involving 2-players game theory and context information of forwarding-node. By making the receiver-node play an active role in the selection of forwarding-nodes, the way introduced by this paper optimize the performance and load of the receiver-node which improve the efficiency of data delivery as a result.

Becker [8] introduced EF (epidemic forwarding) method, which in fact is a flood algorithm. In the EF method, each node has a message queue. When two nodes meet, they exchange information that the opposite party doesn't carry. In this way, a message has many copies in many nodes through the process of exchanging extra message. In condition of enough bandwidth and memory, adopting EF method will ensure to find the shortest path to target node. But in actual circumstances, especially when the bandwidth and memory are limited, as the bottlenecks of Opportunistic Network increasing, the performance of EF method will be weakened rapidly with the broadcast message.

Wang etc. [9] proposed a forwarding mechanism based on coding. And Widmer[10] involve the network coding into the Opportunistic Network. In their researches, they code the transmitting data into abundant messages first, and then send such messages into the forward nodes. By this way, it controls the cost of network. But also brings new cost of computing in transmitting nodes.

Mascolo etc. [11] made an attempt to propose a SCAR (sensor context-aware routing) mechanism in mobile sensors network. In SCAR, the forwarding probability of each node is not based on the status of node-meeting as mentioned before. On the contrary, the forwarding probability comes from the context information of the nodes, including the change rate of neighbors and power energy. The SCAR use Kalaman Filter to predict the change of context information of node, use multi-attributes effect method to estimate the forwarding probability. Both results of the two computations are used to judge the forwarding. By this way, the SCAR can improve the reliability of transmission and control the cost of network. But the SCAR works differently in different network environments, and moreover the computations are too complex.

This paper is organized as follows. Section 2 introduces the context information used in the paper and the future tendency. The usage of game theory related to our approach is discussed in Section 3. The description and result of the simulations is provided in Section 4. Finally, in Section 5 we draw a conclusion about our work in this area.

II. Context Attributes of Forwarding Node

A. Forwarding Node and the Dilemma

In the Opportunistic Network, although the connected-regions are often in the mode of interruption, there are still some overlaps among them due to the movement of the mobile devices of the connected-regions. While the overlap happening, the data stored in the devices in the overlap can be exchanged to forward the data. And such devices are so called forwarding nodes. In order to forward data, there are some algorithms [9]~[13] to judge is it necessary to forward or not. But those algorithms put the jurisdiction to the senders, not receivers. And the receivers have to accept the forwarding data even if it is overloaded. In such cases, if the receivers can join in the forwarding decision, the forward process will be more efficient and the load of receiver will be more balancing. This paper aims at increasing the efficiency of receiver nodes during the decision making process.

B. Context Attributes

There are many context attributes in each node, such as node position, history movement path and rest energy. If take all of them into account, the computation will be huge and complex which is not fit for the mobile devices. So, in our study, we choose some important attributes as below:

(1) Meeting Probability (M):

The Meeting Probability of Node means the probability of communication with the target node during the movement of the node. The bigger the value is, the more chance as a neighbor of the target node emerges.

The initial value of M of the target node is 1, and other nodes are all zero. And the Mi of the node i will be varied as the formula 1 shown.

$$M_i = \begin{cases} aM_i' + (1-a)M_j & \text{i meets j, and } M_j > M_i' \\ bM_i' & \text{time out} \end{cases} \quad (1)$$

$a, b \in [0,1]$, and M_i' is previous value of the node i. When node i meets node j and $M_j > M_i'$, the value of M_i will be computed by the method of 'exponential weighting slide average computation'. And here is a weight value meaning of history probability. If the node i doesn't meet node j with the condition of "$M_j > M_i'$", the value of meeting probability of node i will be changed while the time runs out. And b is the aging factor.

(2) Residual Energy (E):

The definition of Residual Energy of Mobile Node I (E_i for short) is as below:

$$E_i = \frac{E_c}{E_{max}} \quad (2)$$

Here the E_c is the current energy of node i. E_{max} is the max energy of Node i. The bigger of the residual energy is, the rest of working time is longer, and the probability to the target node of the message is bigger.

(3) Forward Weight (P):

Every message has been associated with a Forward Weight, which means the important level of the message. The value of P is smaller, the forwarding of the message is more urgent. The initial value of P is set with the message in the source node, and the initial value is according to the urgent level of the message to the applications. While the message is forwarded among the forwarding nodes, the time of spent in the network become longer, and the message is more urgent to be sent to the target node. The definition of P_m is:

$$P_m = \begin{cases} (1 - M_j)P_m' & \text{i meets j , forwarding message} \\ (1 - \alpha)P_m' & \text{i meets j , but no forwarding} \end{cases} \quad (3)$$

Shown as above, M_j is the Meeting Probability of Node j. P_m' is the old value of the message M. α is a balance constant.

(4) Occupying Space (R):

Every message will occupy some space of the node. Here we use R_m to mean the space of message m. The value of R_m is stable during the forwarding process.

C. Prediction of the context information attributes using Kalman filters

If it is possible to predict future values of the attributes described in the context, it is possible to update the delivery probabilities used by node's negotiation mentioned in section III, even if fresh information is inevitable.

Fortunately, it is possible to express this prediction problem in the form of a state space model. We have a time series of observed values that represent context information. And it is worth noting that one of the main advantages of the Kalman filter is that it does not require the storage of the entire past history of the system, making it suitable for a mobile setting in which memory resources may potentially be very limited.

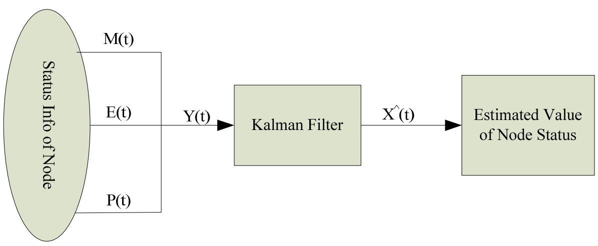

Figure 2. The central filter structure

Kalman filter prediction techniques [16] were originally developed in automatic control systems theory. These are essentially a method of discrete signal processing that provides optimal estimates of the current state of a dynamic system described by a state vector. The state is updated using periodic observations of the system, if available, using a set of prediction recursive equations. The Kalman filter has many structures. Here we choose the central filter structure. See as figure 2.

In the structure of above, the state equation is:

$$X(\tau) = AX(\tau - 1) + w(\tau - 1) \quad (4)$$

here: A is an observed sparse matrix; $X(\tau)$ is the signal vectors at time τ, and

$$X(\tau) = [x_1(\tau)x_2(\tau)x_3(\tau)]^T \quad (5).$$

$x_i(\tau)$ represent the state parameters at time τ; $w(\tau - 1)$is a noisy matrix.

And the measurement equation is :

$$Y(\tau) = CX(\tau) + v(\tau) \quad (6)$$

Here: C is a measurement coefficient matrix; $Y(\tau)$ is the signal measurement vectors at time τ, and the value of vectors is the measure value to $X(\iota)$,

$$Y(\tau) = [y_1(\tau)y_2(\tau)y_3(\tau)]^T \quad (7)$$

$v(\tau)$ is a noisy matrix for measurement process.

Set the estimate-error-vector to signal $X(\tau)$ at time τ is $e(\tau)$, and

$$e(\tau) = X(\tau) - \hat{x}(\tau) = \begin{bmatrix} x_1 & \hat{x}_1 \\ x_2 & \hat{x}_2 \\ x_3 & \hat{x}_3 \end{bmatrix} = \begin{bmatrix} e_1(\tau) \\ e_2(\tau) \\ e_3(\tau) \end{bmatrix} \quad (8)$$

Set the covariance matrix of error-vector is $P(\tau)$, and

$$P(\tau) = E[e(\tau)e^T(\tau)]$$

$$= \begin{bmatrix} E[e_1(\tau)]^2 & E[e_1(\tau)e_2(\tau)] & E[e_1(\tau)e_3(\tau)] \\ E[e_2(\tau)e_1(\tau)] & E[e_2(\tau)]^2 & E[e_2(\tau)e_3(\tau)] \\ E[e_3(\tau)e_1(\tau)] & E[e_3(\tau)e_2(\tau)] & E[e_3(\tau)]^2 \end{bmatrix}$$

$$= \begin{bmatrix} P_{1,1}(\tau) & P_{1,2}(\tau) & P_{1,3}(\tau) \\ P_{2,1}(\tau) & P_{2,2}(\tau) & P_{2,3}(\tau) \\ P_{3,1}(\tau) & P_{3,2}(\tau) & P_{3,3}(\tau) \end{bmatrix} \quad (9)$$

Based on the optimization of filter mean square error, we deduce formulas as below:

$$\hat{X}(\tau) = A\hat{X}(\tau - 1) + K(\tau)[Y(\tau) - CA\hat{X}(\tau - 1)]$$
(10)

$$K(\tau) = P_1(\tau)C^T[CP_1(\tau)C^T + R(\tau)]^{-1} \quad (11)$$

$$P_1(\tau) = AP(\tau - 1)A^T + Q(\tau - 1) \quad (12)$$

$$P(\tau) = P_1(\tau) - K(\tau)CP_1(\tau) \quad (13)$$

And $\hat{X}(\tau)$ is the filter estimate value to the signal vector at timeτ; $Q(\tau)$ is a system covariance matrix of the filter; $R(\tau)$ is an observed covariance matrix for partial Kalman filter; $K(\tau)$ is a gain matrix.

Considering the formulas above and the observed value of the movement of mobile nodes, we create the central filter combing model as:

State Equation:

$$X(\tau) = AX(\tau - 1) + w(\tau - 1) \quad (14)$$

Measurement Equation:

$$Y(\tau) = CX(\tau) + v(\tau) \quad (15)$$

And $Y(\tau)$ is the state vector value when the message is be τ^{th} forwarded, which includes the parameters of Meeting Probability, Residual Energy, Forward Weight and Occupying Space. C is a measurement coefficient matrix, and $C=[C_1C_2C_3]^T$; $v(\tau)$ is a measurement process noisy matrix and $v(\tau)=[v_1(\tau)v_2(\tau)v_3(\tau)]^T$。

From the recursive algorithm of vector Kalman prediction, we can get the solution of equations as below:

$$\hat{X}(\tau)=A\hat{X}(\tau-1)+K(\tau)[Y(\tau)-CA\hat{X}(\tau-1)] \quad (16)$$

$$K(\tau)=P_1(\tau)C^T[CP_1(\tau)C^T+R(\tau)]^{-1} \quad (17)$$

$$P_1(\tau)=AP(\tau-1)A^T+Q(\tau-1) \quad (18)$$

$$P(\tau)=P_1(\tau)-K(\tau)CP_1(\tau) \quad (19)$$

III. FORWARDING DECISION BY 2-PLAYERS NON-COOPERATIVE GAME

The Game Theory is a subject to make self-decision of the players considering the conflict among them [14]. While two nodes meet, a decision of whether forward the message of them or not should be made. In this paper, we seem both mobile nodes as two players, and want to use game theory to solve the forward-decision optimization problem.

A static non-cooperative game model is represented as $G=(P,S,U)$. P is a set of participants who are main part of the game; S is a space of strategies, and it includes all available behaviors of all players. U is a set of efficient functions which means the profit got from the strategy of the players.

In Opportunistic Network, the sender node (named AP) ask forward requirement to receiver node (named TP), and the TP will decide whether to accept the requirement or not. The conflict of both is whether to agree the forward requirement or not. If we use game theory model to consider the whole process between TP and AP, we will find it just a 2-player game theory. And the detail of the model is shown as below:

Participants Set: P={AP,TP};

For AP and TP, the negotiation has only two chioces: one is Agree co-operation (i.e. AP choose forward the message to TP and TP agree to receive it), the other is Refuse co-operation (i.e. Neither AP nor TP doesn't forward the message). Here we use value of 1 to mean the Agree and the value of 0 to mean the Refuse. $s_i=\{0.1\}\ \ i\in P$

To every node i, it has one efficient function: $u_i=u_i(s)\ \ i\in P$; $U=\{u_i\}\text{is a set of efficient function}$. The efficient function of node i is consist of two parts: one is the profit from forwarding the message, and the other one is the cost of forwarding the message.

While AP selects a strategy, the context attributes (M, E, P, R) may be changed because of the selection. And x_{ap} is used to represent the predictive cost value, which come from the Kalman filter predicted by two observed parameters of E and R. In the same way, we set y_{ap} to represent the predictive profit value, which come from the Kalman filter predicting from two observed parameters of M and P. If the AP choice strategy: $s_{ap}=1$, both x_{ap} and y_{ap} will be changed. And on the other hand, if the AP choice strategy: $s_{ap}=0$, x_{ap} won't be changed and y_{ap} maybe varied with time.

Similarity, if TP select strategy: $s_{tp}=1$, xtp and ytp will be re-computed both; if TP select strategy: $s_{tp}=0$, No any change happened for x_{tp} and y_{tp}.

Summing up the strategies and efficient of TP and AP as above, we can get the Payment Matrix. See as Table I:

TABLE I. PAYMENT MATRIX OF 2-PLAYER GAME

		TP	
		0	1
AP	0	$-y_{ap}$, 0	$-y_{ap}$, $x_{tp}-y_{tp}$
	1	$x_{ap}-y_{ap}$, 0	$x_{ap}-y_{ap}$, $x_{tp}-y_{tp}$

From the matrix, we can get the Nash Equilibrium, and then make the decision of TP.

In this game, if a strategic combination of (s_{ap}^*,s_{tp}^*) is existed and it meets that meet the in-equation as below:

$$\left.\begin{aligned}(x_{ap}^*-y_{ap}^*)\geq(x_{ap}-y_{ap})\quad\forall s_{ap}\\(x_{tp}^*-y_{tp}^*)\geq(x_{tp}-y_{tp})\quad\forall s_{tp}\end{aligned}\right\} \quad (20)$$

Then we think the combination is a Pure Strategy Nash Equilibrium. To find the Nash Equilibrium of this game, we choose the way of solving optimal reflect function [16]. And when AP meets TP, both of them use such strategy combination to make a decision of whether forwarding the message or not. By this way, the TP can take part in the forwarding decision and will be used more efficiently.

IV. SIMULATION

A. Compared with some usual algorithms

In our simulation, we choose DTNsim2 [17] simulation platform and realize our forwarding message algorithm (named GT2) based on non-cooperation game in it. For comparison, we select the EF algorithm [8] and CAR algorithm [12] in the simulation, and to analysis the performance among those three algorithms.

All key parameters of the simulation show as table II.

TABLE II. KEY PARAMETERS IN SIMULATION

PARAMETER NAME	VALUE
Region Size	4500M*3400M
Node Of Terminals	16
Message Size	400kbyte
Bandwidth	800Kbps
Simulation duration	5days
Message account for delivery	8
Good Forwarding Nodes	4

The simulation scene is likely the condition discussed in [22], which is from the statistics of study to users' movement equipped with mobile devices. In the scene, the terminals appear with different frequency in every 'Network Center', such as dinner-room, classroom. And both terminals in the same ‘Network Center’ at the same time can identify and communicate each other.

The terminal movement model is a Node Movement Model [23], which comes from the study of Ghosh analyzing the mobile users’ movement in ETN Zurich school. In the model, each terminal exists in every place of ‘Network Center’ with different probability. When two terminals appear in a ‘Network Center’ at the same time, both of them start communication each other. The movement of terminal has some regularity and some random. The movement of terminals seems randomly, but some terminals appear in some ‘Network Center’ more likely than others. And the probability of appearance for each terminal in every ‘Network Center’ has some regularity. Also, the terminals with similarity probability in the same ’Network Center’ has more communication chance than other terminals.

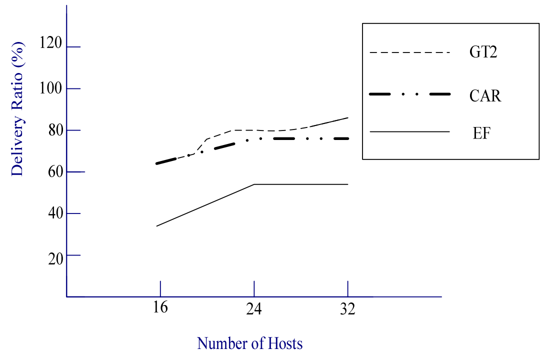

Figure 3. The relation between hosts and delivery rate

In the same simulation environment, we run all three algorithms with the same parameters and settings. Then we collect the result of simulation and analysis in different points. Below is the detail about the simulation results.

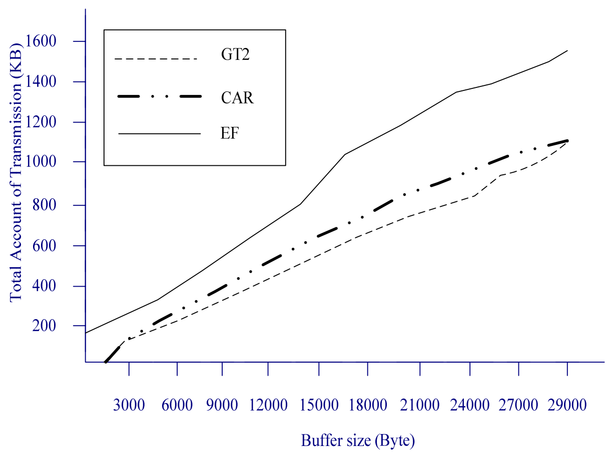

Figure 4. The relation between Memory and Total Account of Transmission

In figure 3, there is a comparison between the delivery ratios of the three algorithms in each of three different scenarios (with 16, 24 and 32 hosts). In all case, the number of messages that may coexist within a node’s buffer is unconstrained.

From the figure 3, we find that the delivery rate of GT2 is better than CAR and EF. And the performance becomes perfect with the growth of hosts. EF is a flood algorithm, which suffers from the inability to deliver messages to recipients that are in other centers when message are sent. But it is simply as a comparator to demonstrate the numbers of messages being delivered that can’t be delivered directly. The CAR algorithm can be considered a optimal in terms of delivery ratio. The CAR is only ever a single copy of each message, which represents the worst case for this protocol. Clearly it would be possible to trade off a small amount of intelligent replication (to improve the delivery ratio) against an increase in overhead.

Figure 4 shows the total number of message in the region with different buffer size. From the figure, we find the performance of GT2 is the best. With the same memory, it is taken less transmission cost to send the same number of messages, as shown with Figure 4. The reason of the advantage comes from the game-theory involved in GT2. Each forwarding node is selected and optimized, but not blindly or based on some simple parameters-comparisons. So GT2 can avoid cost of some unnecessary forwarding process.

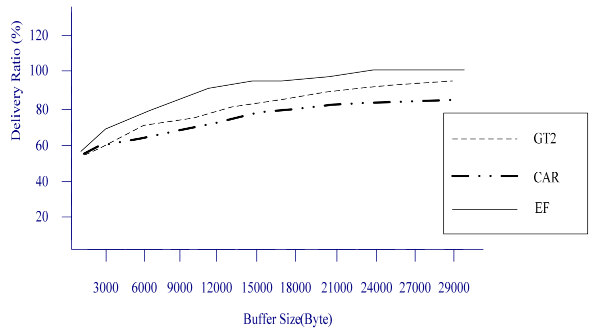

Figure 5. The relation between buffer size and delivery ratio

Figure 5 is a curve graph come from the data of delivery ratio. In the experiment, we set the bandwidth and nodes are fix number, here is 16. And we adjust the buffer size to check the delivery ratio.

From the Figure 5 above, we will find that the delivery rate of GT2 is better than CAR. Although the delivery rate of EF is better than GT2, but the EF is a flood algorithm and has too many others disadvantages. So compared among all, GT2 is still a recommendatory algorithm.

B. Compared with some Cooperation algorithms.

As mentioned in [18], SAR algorithm is abbreviation of Spatially Awareness Routing, which is a router algorithm for MANET based on space information. SAR is cooperation algorithm of each nodes in the MANET.

To build the simulation environment, we did the preparation as below:

We use a region of map of Stuttgart city as simulation area, which size is maybe 2500m*1800m. See as Figure 6.

In the space model of such region, there are 54 nodes and 59 edges linking to some nodes of them. The storage size of the whole space model is less than 2KB, so all nodes in the MANET can visit the space model locally.

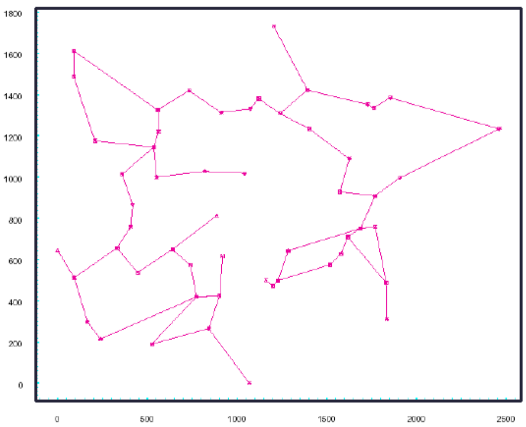

Figure 6. Simulation Region Map

In the experiment, we select node-movement model based in graph [19-21] to simulate the car moving in the region. All terminals select two nodes in the model randomly as start and destination, and move along the shortest path of the two nodes in the space model. The moving rate of terminal is between 38km/h and 60km/h. when the terminal reach the destination, it stop and wait 10s-30s, then start next movement.

In the simulation, the accounts of terminal is 100, the radius of communication is varied from 50m to 250 to make the different node density. The duration time for each test is 900s, and there are 20 CBR application simulated for the experiment. Each CBR is sent by 2Kbps, and the package size is 64B. Table III showed some key parameters in the simulation.

TABLE III. KEY PARAMETERS IN SIMULATION

PARAMETER NAME	VALUE
Test Time	900s
Node of terminals	100
Region Size	2500M*1800M
Radius of Communication	50--250m
movement rate of terminal	30-60km/h
wait time of terminal	10-30s
application type	CBR
application flow	2Kbps
Package Size	64byte
Link nodes	20

In the simulation, the initial probability of node is selected in set [0, 1] randomly.

And to compare the result, we use the term "package delivery ratio" as quantitative measure, which means the ratio of packages reach the destination successfully. And in the experiment, we tested six times for each radius of communication, and the result is a average result of the six test results. See Figure7

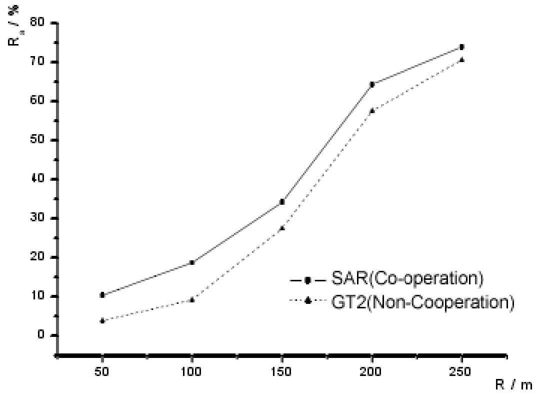

Figure 7. The Package delivery ratio with Radius

Figure 7 showed us the performance comparison of two algorithms in different radius. See as Figure 7, because the SAR based in the consumption that each nodes co-operation well, it performs better than GT2(our non-cooperation algorithm). And this comparison advantage is big when radius is small. The reason of it is that because the density is slow when radius of communication is small, and the success ratio of delivery is small. So the terminals more likely select strategy of '0' to protect itself benefit. With the growth of radius, the density of nodes become bigger, and the ratio of success of delivery is increased. So the possibility of the terminals select strategy of '1' is increased. From the figure, we can find that the GT2 is near SAR when radius of communication is bigger than 200m.

IV. CONCLUSIONS & FUTURE WORK

In this paper, we prompt a new algorithm to solve the problem of optimizing the process of selecting forwarding nodes. With the applying technology of game theory, we make the receiver node take part in the decision of message forwarding. By using the way of two-players non-cooperative game theory, the reciever and sender can discussed the effect of the deliverying, and then draw a conclusion to delivery or not. And the decision of forwarding will be taken account of conditions of sender and receiver, which make the forwarding more reasonably and efficiently.

In the near future, we are to work in two aspects.

Firstly, in this paper, we use Kalman filters to predict the status values for some parameters. Although Kalman filter has good efficience, the computation of it is complicated for mobile device with weak computation power and memory. So in the next step, we will work to find another optimal way to get the predict status value of parameters.

Secondly, here we use a single theory of game theory, i.e. 2-player non-cooperation theory. It's advantage is the computation simple, but it doesn't consider the intelligence of terminal nodes. In the next step, we will make more studies of game theory and try to make the decision of forwarding much more better soon.

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