Based on Place & Driver & Traffic Management: Autonomous Message Mechanism in Urban VANETs

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Abstract. Different from most of the work in vehicular ad hoc networks, which has focused on short periods of transient opportunistic contacts, in our previous work, we have analyzed the monitor data of a large set of urban private vehicles and proposed a Location based Urban Vehicular network (LUV) utilizing the stable connections among parking vehicles. In this paper, we develop an autonomous two-tied message mechanism for LUV. Following driver's path-selecting for vehicle, the message flow in LUV is consistent with the traffic flow in urban. The entire network performance of message transmission is guaranteed by the effect of external urban traffic management. For promoting QoS of message exchange within places, a method is proposed by deploying message center to provide message storage and forward services within places. We perform experimental study over a real dataset gathered over two months for 8900 vehicles, which show that the message mechanism is effective.

Keywords: "urban VANETs" "message mechanism" "message center"

1 Introduction

Owing to the high mobility of vehicles, spatiotemporal diversity of traffic density, and dynamic wireless transmission environment, VANETs present tremendous challenges to the networking community [1]. Given the complex environments and massive number of vehicle nodes, Urban VANETs, as a special case of VANETs, are in particular demanding in providing a reliable and scalable network platform.

While many research studies have strived to circumvent short period, transient opportunistic contacts and corresponding uncertainty arising from the high mobility of vehicles [2,3,4], we focus mainly on the stationary state of vehicles. Through analyzing real trace data, we discover that stationary is a dominating feature of privately owned vehicles, notably different from public service vehicles (for example, buses and taxies). These privately owned vehicles, accounting for roughly 90% of total vehicles, can provide long periods of stable contacts at their visited places. Motivated thereby, we proposed a location base framework for vehicular networks, termed Location based Urban VANETs (LUV) [5], which utilizes stable contacts within places among vehicles that can provide more predictable connections.

In this paper, we present an autonomous two-tier message mechanism for LUV. The message mechanism obeys the laws of existing urban traffic system. By keeping message flow consistent with traffic flow, the efficiency of message transmission between places is guaranteed by driver and urban traffic management. Moreover, we introduce message center for promoting quality of message exchange within places. And a method is proposed to deploy message center in local nodes. For verifying the message mechanism, we analyze a real set of data gathered in an urban environment and prove that sufficient stable local nodes exist to build message center system within places, and the message mechanism provide reliable connections between places.

2 Related Work

Extensive research has been devoted toward vehicular network, focusing on different aspects including routing, neighbor discovery, capacity, security, and privacy [6,7,8]. The constantly changing network topology of VANETs has attracted a plethora of work on designing suitable routing protocols. Flooding is the simplest way to achieve high delivery ratio, while potentially introducing costly contentions and broadcasts storms [9]. Location-based routing protocols have been proposed to exploit geographical location information of nodes in order to support efficient and scalable routing in ad hoc networks [10]. A grid based scheme is presented in [11] for routing in vehicular networks, showing the number of messages carried in the network can be reduced. No characteristics of vehicle movement are considered. A Kalman filter based routing scheme is introduced in [12], where a vehicle's future location is predicted using its historical location information. Vehicles moving with desirable mobility patterns are chosen as intermediate nodes for forwarding. The characteristics of vehicle movements, such as high speed vehicle movement pattern and constrained mobility, have been studied in extensively in the literature [13,14,15]. Based on the results of movement characteristics, various strategies for vehicular networks are developed and have been well experimented through simulation or real life prototyping [16,17,18].

In [5], we found the static of vehicle in areas plays an important role in Urban VANETs. By analyzing a large set of trace data of private vehicles, we draw the significantly different characteristics of vehicles, including dominant parking time, highly repetitive moving pattern, and concentrated visited places. And then we proposed a framework of urban VANETs (LUV) which is based on these characteristics of vehicles. Unlike the former method of VANETs, LUV does not require the assumption they put forward that the data transfer can be always performed successfully during the short contact period of two vehicles or in dynamic surrounding environments. LUV transfers data when vehicles which utilizes stable contacts within the places, where vehicles are either stationary.

3 Message Mechanism in LUV

In this section, we first provide a brief overview of the LUV. Following that, based on the characteristics of privately owned vehicles in urban environment, we develop a message mechanism in LUV for message exchange and transmission in LUV.

3.1 LUV Framework

In LUV, data exchange only happens within a place. While vehicles move from one place to another, on-vehicle data will be carried as well and hence form a network composed of places and linked by moving vehicles.

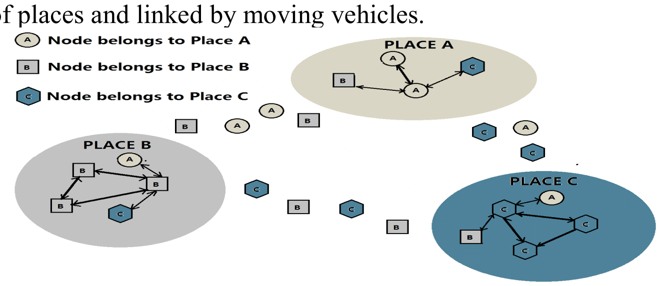

Fig. 1. Framework for Location Urban VANETs (LUV)

Place reaches certain standard of density of local nodes to ensure the local place network has enough resource to work. The belong-place of a vehicle has the longest place residing time and highest place visit frequency. Vehicle has two states in real life: parking state and moving state. The temporary stop of vehicle belongs to moving state. Figure.2 depicts the state switching of vehicle is used to switch node mode for performing different tasks in LUV.

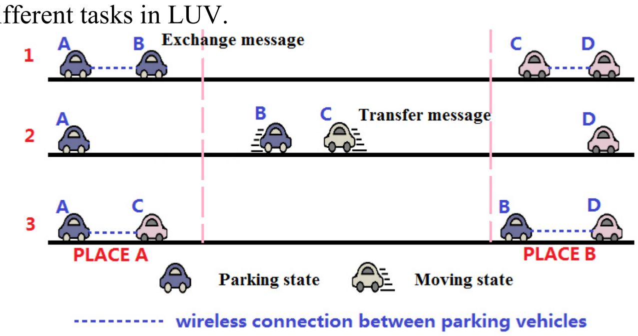

Fig. 2. Node mode switching in LUV

3.2 Autonomous Message Transmission between Places

In past works of VANETs, few work notice the fact that vehicle's movement in urban environment is optimized by driver. Human drivers define the intended driving direction. Considering the factor, we propose an autonomous routing between places by taking human drivers as "intelligent router" in VANETs. When vehicle moves from a place to destination place, the decision of travel route is made by driver. The route results are generally satisfactory for human intelligence. Therefore, keeping carried message consistent with its vehicle, message routing between places happens naturally by following the movement of vehicle.

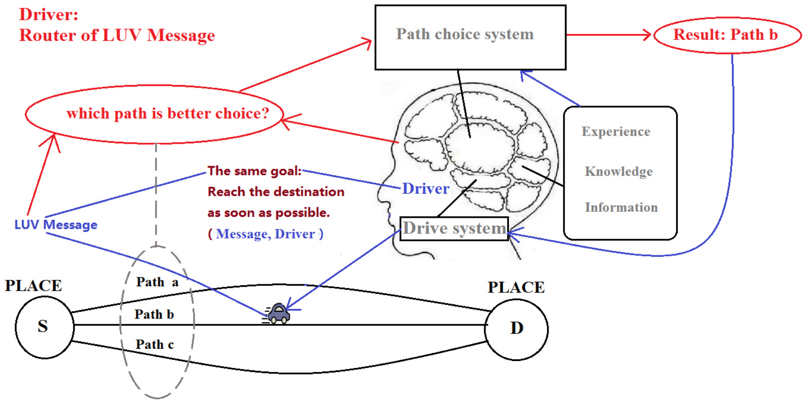

Fig. 3. Autonomous Routing of LUV message between places

Consequently, the traffic flow control in daily traffic management provide network congestion avoiding in LUV. Network connectivity and load balancing of LUV is improved with urban road network constructing. Meanwhile, more vehicles in urban provide the higher communication bandwidth and lower latency. The performance of LUV will promote naturally with the development of urban transportation facilities and management.

3.3 Storage-forward Message Exchange within Place

In this section, for promoting QoS of message exchange, we propose a method of deploying message center to provide message storage and forward services within places. Consulted the classical storage-forward message mechanism in traditional mobile telecom network, we introduce message center which is similar to SMC (short message center) in mobile telecom network for SMS (short message service) [19]. Difference between them is that message center in LUV, as network facility, is dynamically composed by network users (vehicle nodes).

3.3.1 Message Center

Message center provides message storage and forward service within places. If destination node is not in the place or could not be connected, source node send message to message center, and message center will deliver the message to destination node when it returns to the place or be connected by message center. The foreign nodes are forbidden to directly connect message center. Foreign message interface provides a layer of isolation for place sub-network to decrease the system security risk.

Figure.4 depicts the hierarchy structure of message mechanism within places. Message center and foreign message interface are dynamically composed by local nodes according to their stable state at the moment. Foreign message carrier which is a set of foreign nodes and a part of unstable local nodes, is in charge of foreign message transmission with other places. Local consumer is the source or the destination of all messages within places.

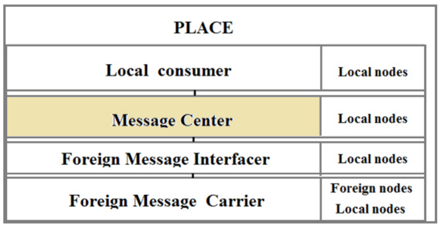

Fig. 4. Hierarchy Structure of Message Mechanism within Places

3.3.2 Deploying Message Centers within Places

Before presenting the deployment of message center, we introduce a parameter of LUV: $Pro\_S_{i,j}^{T}$, the probability of keeping static state in the place j of local vehicle i at time T on a day.

The pattern of a vehicle reside in its belong-place can be drawn from its history GPS track data. $Pro\_S_{i,j}^{T}$ can be obtained from the pattern, and be used to predict the vehicle's behavior at the next moment, continuously stay in or leave the place. We devise the following approach for deploying message center in multiple steps.

a) Obtaining demands of message center in the place

The more local nodes park, the more messages have in the place and vice versa. The demands of message center is proportionate to the amount of local nodes in the place at one moment. By setting the proportion of message center node to local nodes, we can obtain the demands of message center from the amount of local nodes.

b) Electing message center node

Electing local node as message center when its Pro_S satisfies the predefined threshold Th_mc, till the amount of message center nodes fulfill quantity requirement.

Thr_mc: predefined message center threshold of the probability of keeping static state in the place.

Enough value of Thr_mc is necessary to avoid interruption in message center service resulting from message center node leaving. However, the risk of message center node offline cannot be eliminated no matter how large Thr_mc is. A complete set of mechanisms are required to handle the incident, which about message redundancy and message center node's state save and recovery. Length of be confined to, we don't present them in this paper.

c) Renewing the message center nodes by Pro_S

The Pro_S of a message center node varies with time. When it is lower than the predefined threshold Thr_mc, it stops receiving any message at once, and sends the saved messages to other message center nodes. And it tries to find a local node which satisfies the Thr_mc, and transfers its message center token to the new one. After all, the node retires and becomes a local consumer node again.

d) Adjusting size of message center in the place

Message center checks the amount of local nodes within place at regular intervals. When the amount increase, it produces new tokens in proportion, and randomly distributes them to the local nodes which satisfy the threshold Thr_mc. When the amount of local nodes decrease, message center destroys tokens in proportion.

3.3.3 Autonomous Role Transition of Local Node

The status of stabilization of local nodes within places are different in one time. The status of stabilization of node is lower, the probability of node leaving place is higher. When local node's Pro_S is lower than the predefined threshold (Th_fmc), it becomes foreign message carrier. Foreign message carrier is the nodes ready for leaving the place and loading foreign messages. Message center will send them foreign messages. When message carriers leave the place, they will carry these messages to destination place. When they arrive the destination place, massage carriers submit messages to the destination place's message center and receive messages which to their belongs-place. When a message carrier returns, it could carry foreign messages to local message center. When its status becomes more stable in the place, it will turn to local consumer node.

According to the change of their status of stabilization ($Pro\_S_{i,j}^{T}$), local nodes switch their role adaptively. The nodes which have the highest Pro_S act as message center. The nodes which have higher Pro_S act as foreign message interface. The nodes which have normal Pro_S act as local consumer and the nodes which have lower Pro_S act as foreign message carrier.

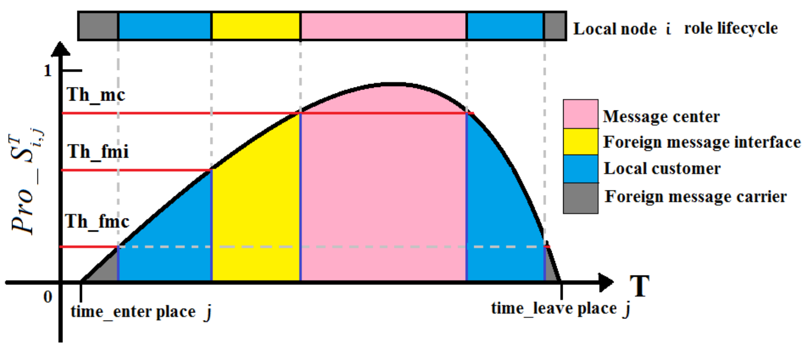

Fig. 5. Autonomous Role Transition of Local Node based on Pro_S

3.4 Advantages of Message Mechanism in LUV

- **Scalability:** LUV is unlimited by the number of nodes. Instead, the more nodes LUV have, the better network performance LUV has in fixed area.
- **Reliability:** The stable data links between stationary nodes improve wireless communication quality. Message center ensures the quality of message exchange within places. Human drivers provide intelligent place routing. Urban traffic management provide network congestion avoiding and load balancing in network.
- **Security:** LUV provides foreign message interface for place to decrease the attack risk from foreign nodes.
- **Privacy:** Vehicle's trace and location information is private in LUV, limited place information of vehicle is open to a small scale in LUV.

4 Experiment Study

In this section, we analyze a large set of trace data on vehicle location in an urban environment in China and prove that the prerequisites of the message mechanism are existing in reality. Moreover, we apply the message mechanism on the dataset and obtain the network connectivity ratio that is 92.3% in LUV. Then we discuss the characters of data link in LUV.

4.1 Real Life Trace Dataset

The dataset is generated by vehicle monitoring terminals, a part of vehicle monitoring system, installed on 8900 private vehicles in Changsha, a city located in the south-central part of China, with a population of 7 million. The GPS data of each vehicle was reported back to the central monitoring system every 30 seconds. However, to reduce the amount of data and redundancy embedded therein, the data was down sampled at a frequency of every 10 minutes each day. The trace data we concerned about was also sampled every 10 minutes. As a result, we got a total of 42,518,112 records spanning 61 days from March to April of 2013. The trace data we use regarding the vehicle locations are quite accurate, as shown in Figure 6.

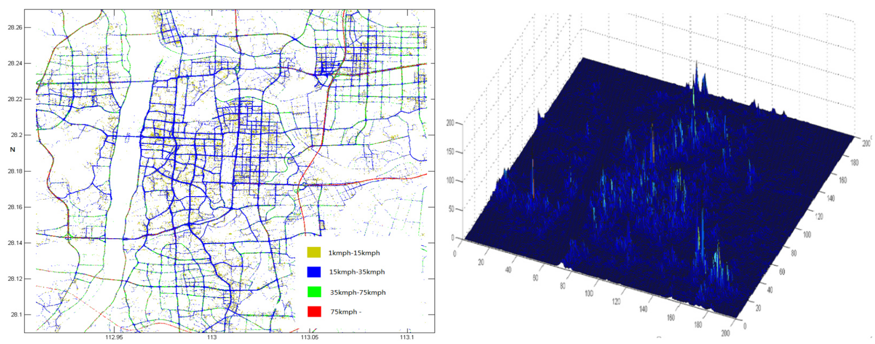

Fig. 6. Spatial Distribution of Moving Vehicles (a) & Parking Vehicles (b) in Changsha

4.2 Empirical Parameters in LUV

In this section, we aim to provide empirical parameters of vehicles for verifying the message mechanism consistent with reality.

- **Daily park time**

The vehicles in Changsha daily park time is 22.63 hour/day. Correspondingly, privately owned vehicles daily motion time is 1.37 hour/day, or 82 min/day. This is a very intuitive results yet contradicting to the assumptions of some studies, where constant movement is usually assumed for all vehicles.

- **All-day park ratio**

For describing the global privately owned vehicle all-day park situation in urban environments, we introduce one key metrics: all-day park Ratio (R_ADP).

$$\text{R\_ADP}=\frac{Days\_AllDayPark}{Days\_statistics}$$

According to the trace data statistics, we get the distribution of Days_AllDayPark in Fig 7. It exhibits a very clear exponential distribution.

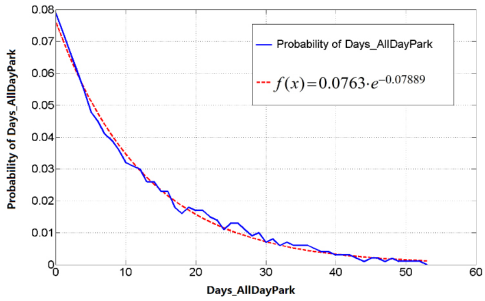

Fig. 7. PDF of Days_AllDayPark & Exponential Distribution fitting

The analysis result indicates that almost one fifth of privately owned vehicles (the expectation of all-day park ratio is 20.79%) is at the state of all-day park in an ordinary day. In past vehicle networks study, the state of all-day park is treated as an extreme and rarely case, which usually is ignored. In this paper, we recognize all-day park is an important factor of urban privately owned vehicle. It proves that place message center mechanism is feasible. All-day parking vehicles in the place is ideal message center node.

- **Resident time in belongs-place**

Resident time in belongs-place is 14.6hour/Activity day and 24hour/inactivity day. It supports that the message mechanism takes local parking nodes as the main part of place and is assisted by foreign nodes and moving nodes.

- **The stable hours number**

Stable hour is given for the situation that vehicle is completely still in one whole hour, thus the vehicle's parking location is fixed at the hour. Significance of Num_SH (stable hours within a day) reflects the vehicle motion frequency. The larger value of Num_SH means the less trip and state switch between station and motion, and more stationary.

By fitting the distribution of Num_SH which be obtained from the statistics of monitor dataset, we find that Num_SH obeys Gaussian distribution with mean 20.88 and variance 2.484 with 95% confidence bounds.

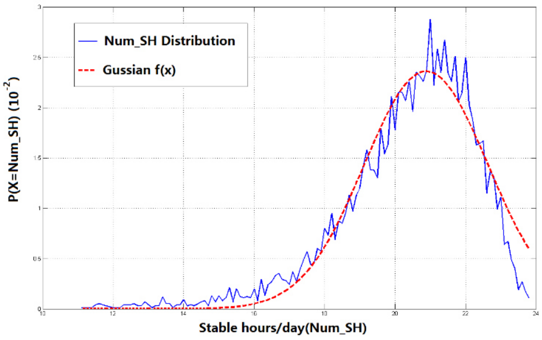

Fig. 8. PDF of Num_SH & Gussian Distribution fitting

Though the privately owned vehicles in Changsha daily park time is 22.63 hour/day, it can't reveal the temporal continuity of urban vehicle's spatial stationary. The stable hour is given for the situation that vehicle is completely still in one whole hour. The stable hour number in Changsha privately vehicles is 21 hour/day. It shows that the temporal distribution of the motion events of vehicle are not disperse, but centralized in a day. If vehicles park in a place, it usually lasts for several hours. It implies that there are comparatively adequate stable nodes within places.

4.3 Place Connectivity Ratio in LUV

In [20], we developed a threshold based approach for identifying the places place identification. We effectively identified 873 LUV places (each with an area of 100m by 100m.) over a 20km by 20km area. However, the amount of local nodes of places which from real date set is not meet the requirement of study the connectivity of places in LUV. 8900 vehicles distribute in 873 places, the average place has 10 nodes. If we set higher vehicle density threshold of place, the places number in LUV will decrease rapidly, the node number in every place is unchanged.

In view of the fact, we zoom in the place area to acquire enough local nodes in one place to study the connectivity of places in LUV over the real life data. We first divide the area, which is 20km by 20km into 25 units, each with an area of 4km by 4km. By a simple threshold based approach for identifying the places, we identified 13 LUV places and 4526 vehicles belong to these places. Besides belong-places, we set a visit place to each node. So we obtain the reliable data links between places. There are 1016 data links between the places. The details of data links as below:

	1	2	3	4	5	6	7	8	9	10	11	12	13
1		6	1	2	3	5	4	2	1	2	0	3	0
2	8		8	5	0	8	10	3	2	3	2	2	0
3	1	7		8	1	3	7	6	2	5	2	3	0
4	3	8	20		3	7	7	4	2	2	5	6	2
5	4	2	3	2		14	5	0	3	8	0	2	0
6	13	9	3	5	7		18	2	9	9	3	6	2
7	10	19	14	6	7	28		35	5	21	12	9	4
8	3	5	9	5	0	3	16		3	7	14	4	1
9	2	1	4	2	3	14	2	3		18	2	9	4
10	6	7	10	7	6	16	26	10	23		41	31	5
11	1	2	3	4	1	1	8	9	3	24		8	1
12	5	5	6	3	6	7	13	6	11	16	12		17
13	1	0	0	1	2	1	2	0	2	8	1	11	

Fig. 9. Details of data links of places over real life data

There are three place pairs which don't have path in two directions. Since it exists 78 paths between the places, thus the LUV network connectivity ratio is 96.15%. Considering the one direction path, there are 12 place pairs that don't have path in 156 place pairs. The place connectivity ratio is 92.3%.

We noticed that there are many paths which have few data links. Can they provide reliable communication in LUV? How dependability it could provide when the paths have only one or two data links?

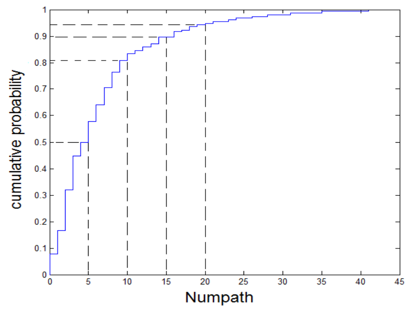

Fig. 10. CDF of data links of places over real life data

Figure.10 shows 50% of paths have less than 6 data links. $Prob\_Link_i^{a,b}$ is the Probability of data link by vehicle i on path(a,b), which depended on the probability of V_i visits its belongs place a($Prob\_Belong_{i,a}$) and the probability of V_i visits its visit place b($Prob\_Visit_{i,b}$). If the path has n data links (vehicle i1,i2,…,in), the path link probability is

$$Prob\_Path^{a,b} = 1 - \prod_{i=1}^{n} (1 - Prob\_Belong_{i,a} \bullet Prob\_Visit_{i,b})$$

When vehicles have the same $Prob\_Belong_a$ and $Prob\_Visit_b$, we can simply the equation as follow:

$$Prob\_Path^{a,b} = 1 - (1 - Prob\_Belong_a \bullet Prob\_Visit_b)^n$$

By setting a set of predefined values of $Prob\_Belong_a$ and $Prob\_Visit_b$ (we set probability of belongs place as 0.95. In fact, we find it would higher over real life data), we obtain the Prob_Path with different number of data links as follow Figure.

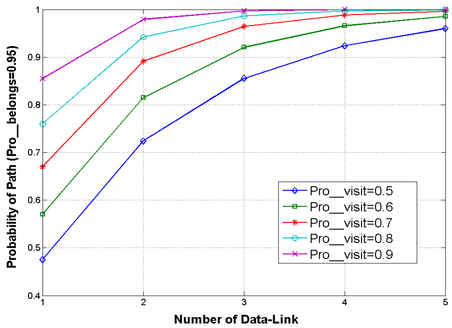

Fig. 11. Prob_Path with different number of data links

As shown in Figure 11, the path more than three links has good dependability. While the paths have only one or two data links, the reliability of the paths depends on the probability of the visit place. Therefore, the mechanism allows us to adjust the dependability of path by setting the parameter of threshold.

5 Conclusion

In urban VANETs, the environments are complex and the number of vehicle nodes are massive. The reliability of message exchange between nodes, and the overhead of message transmission are then significant concers. In this paper, we propose an autonomous two-tied message mechanism for LUV which utilizes stable contacts within places. The message mechanism obeys the laws of existing urban traffic system. By keeping message flow in LUV consistent with traffic flow in reality, without extra network overhead, the efficiency of message transmission between places is guaranteed by driver and urban traffic management in external world. Meanwhile, message center is introduced for promoting quality of message exchange within places. We develop a method of deploying message center in local nodes within places.

For verifying the message mechanism, we estimate the empirical parameters of vehicle on a real set of data gathered in an urban environment. The results show that there are enough stable local nodes resource to build message center system within places. We obtain the network connectivity ratio which is 92.3% in Changsha and prove that the message mechanism can provide reliable connections between places.

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