WaterChat: A Group Chat Application Based on Opportunistic Mobile Social Networks

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Abstract —Recently there are emerging applications based on opportunistic mobile social networks, which are kinds of delay tolerant networks (DTNs) with social relations between the nodes. In such networking scenarios, messages are disseminated through intermittent connections in a store-carry-and-forward manner. A major advantage of the opportunistic mobile social networks includes enabling communication under extreme networking conditions where Internet is unstable or unavailable. However, challenges include limited resources in networking and computing. Network coding is an effective solution to improve the networking performance in opportunistic mobile social networks. We propose a Two-Phase Network Coding solution that uses network coding based on opportunistic mobile social characteristics. Priority of messages is also considered to make the solution more practical for actual applications. To sum up, we introduce a mobile chat application based on the aforementioned, WaterChat, which has enhanced networking performance.

Index Terms—Intermittently connected networks network coding, opportunistic mobile social network

I. Introduction

Recently, there are emerging applications based on opportunistic mobile social networks (MSNs). Firechat [1] enables instant messaging without requiring Internet access, which is a powerful solution in some special scenarios when Internet is unavailable.

The opportunistic mobile social network is a special network formed by mobile nodes communicating with short distance wireless communication capability, such as Bluetooth or WiFi [2], [3]. Such mobile social networks are connected in an opportunistic manner. However, communication in opportunistic mobile social networks is a very difficult task. Inter connectivity formed by short distance wireless communication can open up powerful new possibilities, such as communication without infrastructure, proximity, and recording physical encounters between nodes, but the network suffers from constant disconnection due to nodes' mobility. Other challenges also include limited resources on mobile devices, such as limited energy and computing power.

To overcome the limited resources, we leverage the power of network coding. Network coding is a promising solution for opportunistic mobile social network. Benefits of network coding include improved robustness of network operations, higher energy efficiency in wireless radios, and better security [4]. Network coding requires wireless broadcasting. On mobile devices, using Wifi Direct and Bluetooth Low energy can leverage the advantage of network broadcasting without setting up an infrastructure.

Network coding has been shown to be effective in being applied to the intermittent connected mobile network, [5]. However, in network coding, messages are broken down into coded packets and combined with other coded messages; a message can only be decoded to its original form when all necessary pieces of coded messages have been received in a node. This can be a major issue when applying network coding in intermittent connected mobile network. With limited resources and mobility of nodes, it may take quite a while before all necessary coded messages are fully gathered. Therefore, we propose a "two phase networking" solution, in which messages will be dynamically determined if it will be sent by coded message with network coding, or just simply be sent by its original form to "spray" some copies to the network. After enough initial copies of messages exist in the network, the network can then take full advantage of network coding.

In addition to providing solution for improved message delivery performance with network coding, priorities for messages are also taken into account. Many real applications will require more than the above metrics. For example, some applications may require messages to be delivered within a defined deadline. We propose a "remaining time value of message" scheme, which grants "time value" to messages with different priorities. Messages with higher priority will be delivered to its destination with shorter delivery delay. Priority consideration in routing will be very useful in many real applications. For example, the MSN includes an incentive for a node to deliver a high priority message and nodes that are willing to pay for better networking performance.

Consider an opportunistic mobile social network, and messages to be delivered to its destination with priorities, we choose mobile chat as a sample scenario and evaluation environment for our proposed algorithm. We design a mobile chat application powered by proposed

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two-phase network coding routing: WaterChat, where messages flow and distribute everywhere like water.

Next, we evaluated our approach with real trace data from our previous work, NCCU Trace [6]. The results show that our approach is effective and superior to the flooding based routing protocol and the pure network coding technique. Finally, priority of the messages was handled and results show higher priority messages have shorter delivery time.

II. Background & Network Model

A. Opportunistic Mobile Social Network

The opportunistic mobile social network is a kind of delay tolerant network with social relations between the nodes [7]. Delay-tolerant networking (DTN) is a routing protocol to computer network architecture that may lack continuous network connectivity. There are many DTN routing protocols based on "Store-Carry-Forward", which can be divided into two categories: flooding-based protocol and forwarding-based protocol [8]. In figure 1, the concept of Store-Carry-Forward is that message is sent to an intermediate node where it is kept and sent at a later time to the final destination node or to another intermediate node.

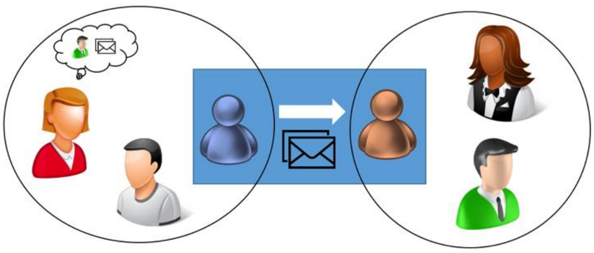

Fig. 1. Store-Carry-Forward

B. WaterChat: MSN-enabled Chatroom

Here we introduce a mobile chat application powered by opportunistic mobile social networks to fully utilize the benefits. In 2014, Open Garden built a messaging application "FireChat" [1]. FireChat is a free messaging App that offers both public and private messaging even without Internet access or cellular data. FireChat has proven its unique capability and gained popularity in extreme cases where Internet access was not available. FireChat enables direct messaging with short-range wireless communication.

We extend the application to support indirect communication, in which nodes can help each other "forward" other's messages to the destination, thus greatly expanding the network coverage.

WaterChat offers a unique feature with the addition of group chatrooms in which users can join. Each chatroom member can forward a different group's message as shown in Fig. 2. The receiving end of the delivered message is a group rather than an individual. Each user can participate in more than one chatroom.

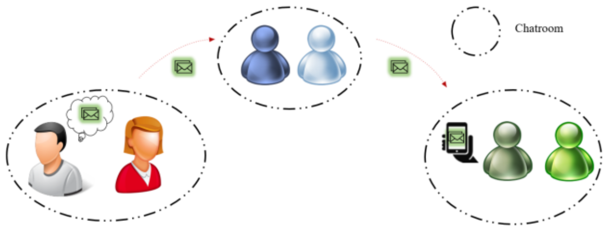

Fig. 2. Experiment environment

Furthermore, users are able to assign and prioritize the new messages that they generate. We illustrate this concept in Fig. 3. Messages that have been assigned as first priority represent the most important messages, and so on. The message dissemination method using advantage of network coding will be addressed in the following sections.

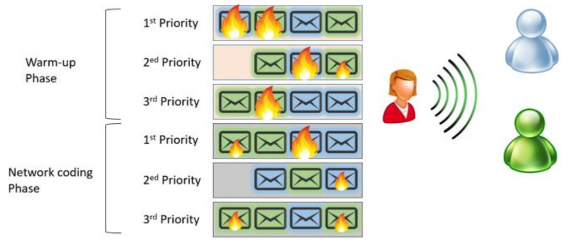

Fig. 3. Architecture of message buffer

III. A Two-Phase Network Coding Design for Mobile Time-Valued Group-Message Dissemination

A. Overview of Proposed Solution

Here we propose a network coding based routing solution for the mobile opportunistic network.

Network coding is used to utilize the limited resource of mobile opportunistic network, aiming to reduce delivery cost and improve delivery ratio. However, when a new message M needs to be disseminated, initially it would be very hard for other users to decode the received message M, since the required coded packets for M for decoding are not yet complete. Therefore, we propose a "warm up" phase to let the network "warm up" with enough decoded messages to solve the initial "hard to decode" issue. Network coding can then be applied to the network and greatly improve message dissemination in the mobile opportunistic network. In addition to two different phases, a dynamically determined threshold is computed to place messages into the specific phase.

Due to the limited resource and mobility of nodes in mobile opportunistic network, the number of messages that can be transmitted from one node to another is limited during each encounter between nodes. Therefore, we propose a forwarding message selection scheme and a message forwarding sequence to select the messages to be forwarded in each encounter.

In the sample application of group chat, users belong to different "groups". During message transmission, messages that belong to the same group of sender and receiver will be selected for transmission, and some of the remaining messages (messages in different groups) will be selected by the sender to transmit. We introduce “Activity Ratio”, which will calculate a user’s probability of meeting a specific group. Messages belonging to receiver’s highest “Activity Ratio” will also be selected, so the receiver will assist the message relay to the group that he will most likely meet.

Since “priority” of messages are strongly considered, the proposed “remaining time value of messages” is used to determine the message forward sequence during the multi-hop message dissemination, with message buffer management schemes. Detailed discussion for the proposed solution will be discussed in the next section.

B. Proposed Solution Details

1) Warm Up phase

In the warm up phase, messages are sent to another user without network coding to ensure messages are delivered with low delay time. We adapt “Spray and Wait” routing protocol for reference, and limit the copies of forwarding messages.

When the forwarded messages reach to its maximum allowed copies, they will be moved to the networking phase, in which they are transmitted in coded-packets.

2) Network coding phase

After new messages are “sprayed” into the network with enough copies, network coding can then be enforced with acceptable packet decode probability.

In network coding phase, messages are first coded by network coding before being transmitted. The network coding phase aims to improve overall network throughput, achieve lower delivery cost, and increase delivery ratio.

3) Dynamic threshold for two-phase network coding

The key to our two-phased network coding solution is to dynamically determine whether a message should be sent in its original form or be coded by network coding.

In addition to the initial coding and decoding problem for network coding in opportunistic network, other problems remain. Due to the different mobility of nodes, some nodes will have a higher chance in contacting with other nodes, while others may have little or no chance. Therefore, such scenario will impact the performance of network coding.

We propose a social-based dynamic threshold adjustment. In the group chat application, nodes join different chat rooms, belonging to different groups. If a message m_i^g belonging to group g is to be carried to its destination g by node N, if N has higher opportunity to contact nodes in group g, the chance of message delivery of m_i^g to g will in turn be high. Since network coding requires broadcasting messages and gathering the necessary coded messages, if a node N has a high activity (contact probability) with group g, the node N can deliver m_i^g with network coding to increase networking performance. On the other hand, the node can deliver m_i^g in its original form without network coding.

We define Activity Ratio, which indicates the activity between a node N and group g:

$$AR_g = \frac{\sum EC_g}{\sum EC_G}, \text{ where } g \in G \tag{1}$$

Activity ratio will be updated periodically and calculated with a sliding window of contact history. Moreover, the activity ratio for groups is "aged" with flowing equation (2). Notation for equation (2) is described in Table I.

$$(AR_g)_{new} = (AR_g)_{old} * \beta,\ g \in G \tag{2}$$

TABLE I: NOTATION FOR ACTIVITY RATIO

Notation	Description
AR_g	Activity ratio for group **g**
EC_g	Encounter Count for group **g**
EC_G	Encounter Count for all group
β	Aging constant

The dynamic ratio for two-phase network coding is defined in the following equation (3):

$$m_i^g = \begin{cases} m_i^g \in Ph_{\_warm}, & if\ r_{m_i} + o_{m_i} < Th_{m_i} \\ m_i^g \in Ph_{\_nc}, & if\ r_{m_i} + o_{m_i} \geq Th_{m_i} \end{cases}$$
$$\forall i, g\ ;\ m_i^g \in M\ ;\ g \in G \tag{3}$$

To calculate the threshold Th_{m_i} dynamically, the remaining copy and the social activity of a node carrying message m_i^g is considered, with a tuning parameter:

$$Th_{m_i} = RN(m_i^g) * \gamma * (1 - AR_g)_{receiver}$$
$$\forall i\ ;\ m_i^g \in M \tag{4}$$

The higher AR_g implies that the node will have higher chance to contact other nodes in group G and deliver the message m_i^g, therefore (what) will more likely be sent in network coding phase. Notation for equation (3) and (4) is described in Table II.

TABLE II: NOTATION FOR DYNAMIC THRESHOLD

Notation	Description
m_i^g	Message **i** of group **g**
r_{m_i}	Total relayed messages
o_{m_i}	Total overheard messages
Th_{m_i}	Threshold for message **i**
$Ph_{\_warm}$	Warm up phase
$Ph_{\_nc}$	Networking coding phase
$RN(m_i)$	Remaining relay copies of message **i**
γ	Network environment constant
AR_g	Activity ratio for group **g**

4) Routing strategy

In this section, we introduce our proposed two-phase network coding routing protocol in detail.

The message dissemination flowchart for the proposed protocol is shown in Fig. 4.

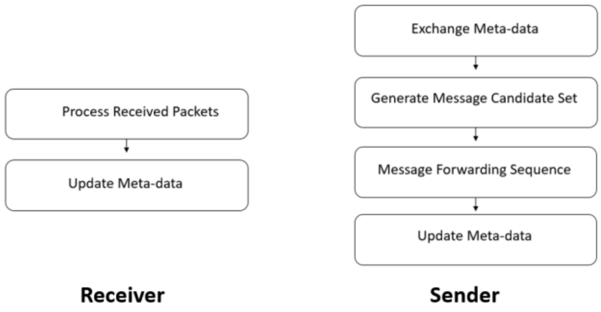

Fig. 4. Flowchart of routing strategy

5) Exchange meta-data

If two nodes encounter each other, firstly they will exchange meta-data, such as history table (HT) and un-coded message list (UML). History table is shown in Fig. 5. The attribute of TS (Time stamp) is calculated by comparing the current system time and activity ratio updated time, which is used to remove outdated information. The attribute of Member is used to identify the group member in the chatroom. In figure 6, UML is the un-coded message list, illustrating the most recent node that has been received or decoded.

Group_ID	AR	TS	Member
1	0.81	3352	T
2	0.52	4760	F
3	0.34	2525	T
4	0.38	3005	F
5	0.56	4298	F

Sender

Group_ID	AR	TS	Member
1	0.56	4452	T
2	0.71	4866	F
3	0.35	3921	T
4	0.49	3603	F
5	0.15	2639	F

Receiver

Fig. 5. History table

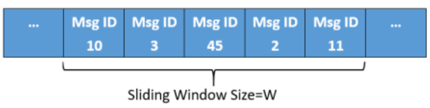

Fig. 6. Un-coded message list

6) Generate message candidate Set

The sender will choose specific group messages to temperate buffer randomly by analyzing the History Table. For example, the sender will choose the intersection member' messages into candidate set. Besides, group message with highest activity ratio will also be selected into the candidate set. Next, each message will be classified into different phases based on their thresholds, and finally we will obtain three sets (S_1, S_2, S_3) as indicated in the following equation (5).

$$S_1 = \{m_i^g \mid m_i^g \in Ph_{\_warm}\}$$

$$S_2 = \{m_i^g \oplus m_j^g \mid m_i^g \in Ph_{\_warm} \times m_j^g \in Ph_{\_nc}\}$$

$$S_3 = \{m_i^g \oplus m_j^g \mid m_i^g \in Ph_{\_nc} \times m_j^g \in Ph_{\_nc}\}$$

$$\forall i,j,g\,;\ m_i^g, m_j^g \in M\,;\ g \in G$$

$$\text{CS} = S_1 \cup S_2 \cup S_3 \tag{5}$$

7) Message priority and its remaining time value

Assume a message needs to be delivered to the destination as soon as possible.

The message's value will decrease over time. We use the exponential decay formula shown below to define time decay:

$$\frac{dv(t)}{dt} = -\alpha v(t)\ ,\ v(t) = v_0 e^{-\alpha t} \tag{6}$$

$$TV(m_i) = \begin{cases} v_0 e^{\frac{-t}{\alpha * P_{m_i}}}, & if\ t < TTL \\ 0\ , & if\ t \geq TTL \end{cases} \tag{7}$$

$$\text{Let } t = \left\lfloor \frac{T\text{-}CT_{m_i}}{Per} \right\rfloor;\ \forall i, m_i \in M$$

where v(t) is the function of remaining time value, v_0 is the initial remaining time value, and α is the Exponential decay constant. Messages will have a maximum life, denoted as TTL.

Our algorithm aims to shorten the expected delivery time as the priority of the message increases. Also, ideally the receiver will receive messages with as much remaining time as possible. The messages with higher priority will receive a higher initial remaining time value v_0. Therefore, it would be beneficial for a node to receive a higher priority message over a lower priority message, for $V_{Higher}(t)$ and $V_{Lower}(t)$ at t_1. However, a message with higher priority would be more sensitive to delivery delay, thus receiving a higher priority message after a long delay will receive a lower remaining time value than lower priority message, for $V_{Higher}(t)$ and $V_{Lower}(t)$ at t_2, where $t_1 < t_2$. Example for time value for messages with different priorities is shown in Fig. 7. Notation for equation (6) and (7) is described in Table III.

TABLE III: NOTATION FOR TIME VALUE CALCULATION

Notation	Description
$v(t)$	Time value function
t	Time
α	Exponential decay constant
v_0	Initial quantity of time value
$TV(m_i)$	Time value of message **i**
P_{m_i}	Priority of message
Per	Time period constant
TTL	Time to live of message
T	Current system time
CT_{m_i}	Message create time

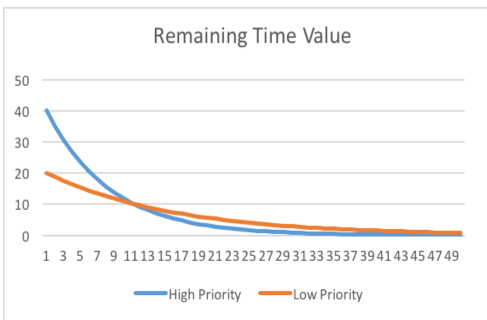

Fig. 7. Remaining time value comparison for message with different priorities.

8) *Message forwarding sequence*

In social opportunistic networks, the contact time of two nodes may not be long. However, the contact is short and unstable due to the mobility pattern of node. Therefore, the sender node probably does not have enough time to transmit all selected candidate sets to the receiver node. The characteristic of carry-and-forward is important in social opportunistic networks. Due to the limited networking resource of each node contact, candidate messages must be carefully chosen. The message forwarding sequence will influence the performance of delivery ratio and delivery delay significantly. Message Forwarding Sequence is shown in Fig. 8. Details for constructing the sequence is described in the following section.

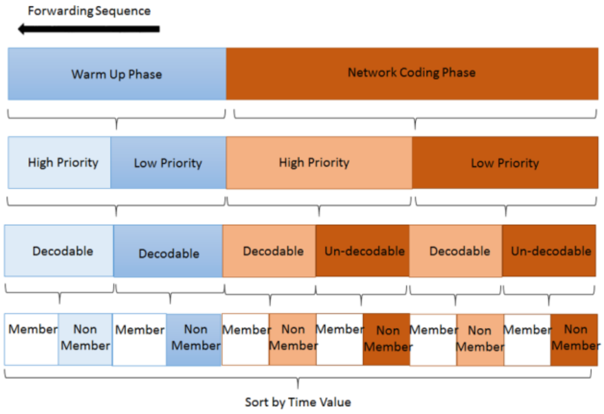

Fig. 8. Message forwarding sequence

9) *Message forwarding sequence*

If messages belong to the warm phase, which means there are few copies in the network, messages need to be "sprayed" into the network. Consequently, the messages of the warm phase should be transmitted in a higher priority. We illustrate our idea in Fig. 8. If two messages belong to the same phase, the transmission sequence will be scheduled by decode probability and remaining time value from equation (7) and (8). The decode probability can be known from the history table and the expected time value can be calculated by following equation (8).

$$\mathrm{TV}\left(m'_k\right) = \begin{cases} \mathrm{TV}(m_i^g) & , if\ m'_i\ is\ uncoded\ , m'_k = m_i^g \\ MAX\left(\mathrm{TV}(m_i^g), \mathrm{TV}(m_j^g)\right) & , if\ m'_i\ is\ coded\ , m'_k = m_i^g \oplus m_j^g \end{cases}$$

$$\forall i,j,k,g\ ;\ m'_k \in FS\ ;\ FS \subset CS\ ;\ m_i^g, m_j^g \in M\ ;\ g \in G \tag{8}$$

Details for the proposed solution is described in Algorithm 1 below:

Algorithm 1 : Generate Message Forwarding Sequence (FS)

Input : Message coded buffer (MB_{coded}), Message Candidate Set(CS) , Maximum Forward Message Size(S_m)

Output: Message Forwarding Sequence (FS)

While $|FS| < S_m$:
    If CS is not $\emptyset$:
        Let M := $Random(CS)$;
        FS.append(M);
        $CS.RemoveByMsg(M)$;
    Else:
        If MB_{coded} is not $\emptyset$:
            Let M := $Random(MB_{\text{coded}})$;
            FS.append(M);
            $FS.RemoveByMsg(M)$;
        Else:
            Break;

$(FS).split(phase)$; // split subset by phase
$FS = S_{ph_{(i)}} + S_{ph_{(i+1)}} + \cdots + S_{ph_{(i+n)}}$
For each subset of phase
    $\left(S_{ph_{(w)}}\right).split(priority)$; // split subset by priority
$S_{ph_{(w)}} = S_{p_{(j)}} + S_{p_{(j+1)}} + \cdots + S_{p_{(j+n)}}$
For each subset of priority
    $\left(S_{p_{(x)}}\right).split(decodable)$; // split subset by decodable
$S_{p_{(x)}} = S_{de_{(k)}} + S_{de_{(k+1)}} + \cdots + S_{de_{(k+n)}}$
For each subset of decodable
    $\left(S_{de_{(y)}}\right).split(member)$; // split subset by member
$S_{de_{(y)}} = S_{mem_{(l)}} + S_{mem_{(l+1)}} + \cdots + S_{mem_{(l+n)}}$
For each subset of member
    $\left(S_{de_{(z)}}\right).sort(timevalue)$;

IV. Simulation Results

We use The ONE (Opportunistic Network Environment simulator) [9] to conduct our simulation and evaluation of our proposed method, which is an open source platform of an opportunistic network simulator.

We extend The ONE simulation software to support simulation of mobile group chat application, based on our previous work, NCCU Trace [6].

In our scenario, we choose NCCU trace data to be our mobility model. The trace data was collected by volunteers of students in a college by an Android App; data include GPS, nearby Bluetooth device scans, WiFi AP scans, and App usage behavior (i.e. when and how long WhatsApp, Tweeter, etc. have been used), which is ideal to create a mobile group chat simulation. Parameters for simulation setting are described in Table IV.

TABLE IV: SIMULATION SETTING

Map	NCCU Trace
Area	3764*3420m
Simulation Time	172800 sec
Radio Range	30m
Buffer Size	100MB
Number of chatroom	5
Priority Level	2

A. *Delivery Ratio*

Delivery ratio is calculated by percentage of messages delivered to the destination(s). Fig. 9 shows that 2-phase networking coding design is better than the other routing methods. In the networking coding (N.C.) only approach, many messages in the buffer are not successfully decoded.

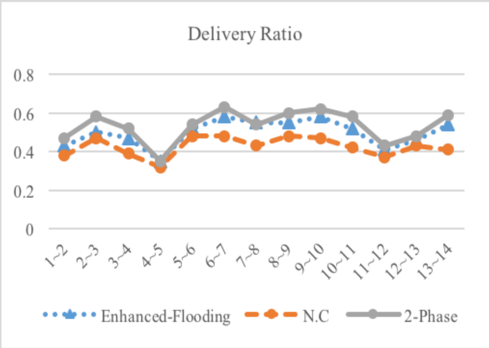

Fig. 9. Result: Delivery ratio

Fig. 10 shows the comparison of delivery ratio for messages with different priorities for the 2-phase method. The simulation result shows that messages with high priority achieve better delivery ratio compared to messages with lower priority.

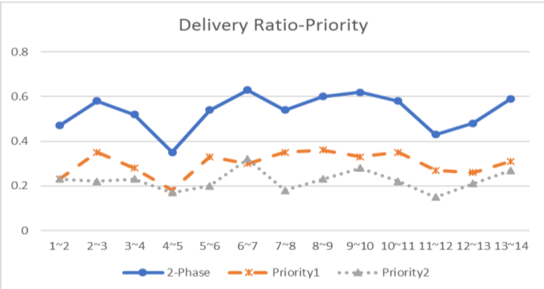

Fig. 10. Result: Delivery ratio-priority

B. Message Delay

Message delay is calculated by the message created time and message delivered time to all nodes. In Figure 11, it is observed that two phase mechanism greatly outperforms flooding in terms of message delivery delay.

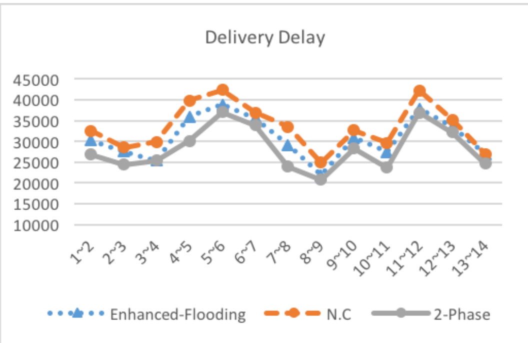

Fig. 11. Result: Delivery delay

C. Remaining Time Value

Time value corresponds to the message priority and delay time. There are two priority messages in the network, and we define messages' time value decay exponentially. High priority messages with larger decay constants make the time value vanish much more rapidly. Next, we define our time value in the semi-open range [0.0, 1.0). Fig. 12 shows that our two phase design is superior to other routing protocols.

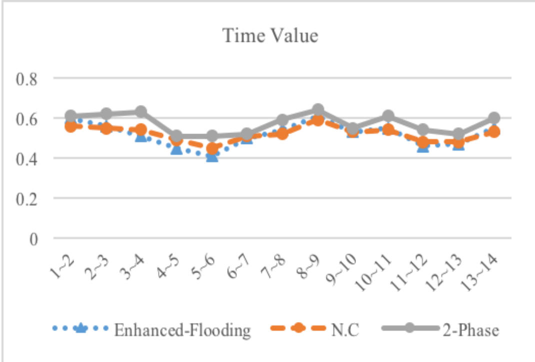

Fig. 12. Result: Time Value

D. Overhead Ratio

In Fig. 13, we can observe that network coding and two phase network coding results in lower overhead than the enhanced flooding.

In addition, two phase network coding results in similar overhead ratio as only network coding.

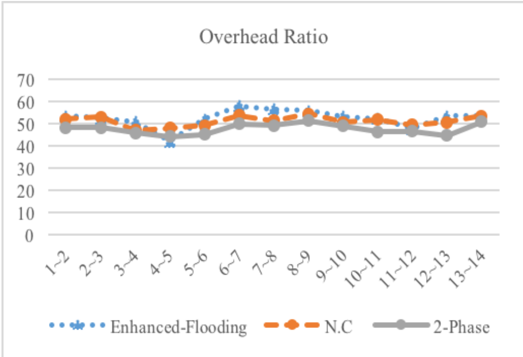

Fig. 13. Result: Overhead ratio

V. Discussion and Conclusion

In this paper, we proposed "2-phase Network Coding Design for Mobile Time-valued Group-message Dissemination" in opportunistic mobile social networks. We designed a WaterChat App as an example to evaluate our method. The Warm Up phase can increase the decode probability in the buffer; moreover, the network coding technique phase can improve network performance. The simulation result shows that our proposed protocol is effective and superior to flooding based message broadcasting in performance of message delivery ratio, message delivery delay and message time value. Furthermore, we evaluated our dissemination approach with real trace data from campus instead of random trajectory.

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