Mobile Social Networking Aided Content Dissemination in Heterogeneous Networks

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Abstract: Since an increasing number of mobile applications are based on the proliferation of social information, the study of mobile social networks (MSNs) relies on the combination of social sciences and wireless communications. Operating wireless networks more efficiently by exploiting social relationships between the MSN users is an appealing but challenging option for network operators. A MSN aided content dissemination technique is presented as a potential extension of conventional cellular wireless networks in order to satisfy the increasing data traffic. By allowing that the MSN users create a self-organized ad hoc network for spontaneously disseminating the contents, the network operator may be able to reduce the operational costs and simultaneously achieve an improved network performance. In this paper, we firstly summarize the basic features of the MSN architecture, followed by a survey of the factors, which may affect the MSN aided content dissemination. Using a case study, we demonstrate that it is possible to economize with the resources of the base station (BS), whilst substantially reducing the content dissemination delay. Finally, other potential applications of MSN aided content dissemination are introduced and a range of future challenges are summarized.

Key words: Mobile social networks, content dissemination, heterogeneous networks

I. INTRODUCTION

Online social networks have become an indispensable part of people's daily lives. While enjoying the services provided by Facebook or Twitter, people create their own virtual communities based on common interests, where they publish their status, post comments, share photos and videos. Following the emergence of smart handsets, people are no longer restricted to their desktop computers, they are capable of interacting with their friends anywhere, any time.

As a result, the wireless network operators are predicting further substantial data traffic growth in the near future. A logical step towards solving this problem for the operators is to further develop their centralized infrastructure by increasing the number of base stations (BSs), and WIFI hotspots, while shrinking the size of the cells. However, when the number of BSs is increased, more power is dissipated for the sake of satisfying the appetite of mobile users, which is costly and contradicts to the concept of green communication. Secondly, as the size of cells shrinks, mobile users have to hand over from one cell to another more frequently, which may reduce the quality of experience (QoE) and impose extra control traffic. Furthermore, mobile users may suffer from more inter-cell interference.

Moreover, people may form temporary communities during a public event, which results in dense pockets of high user population and a sudden significant data traffic growth in a small area. However, building a costly permanent infrastructure for this type of communities is not a wise investment for the operators, since the relevant area may be barely visited after the event. If a temporary ad hoc network can be created by this community based on people's smart multifunctional handsets for content dissemination, the system may be operated efficiently without an expensive infrastructure. Furthermore, by exploiting the functions provided by mobile social networks (MSNs) [1], which are based on a combination of physical mobile networks

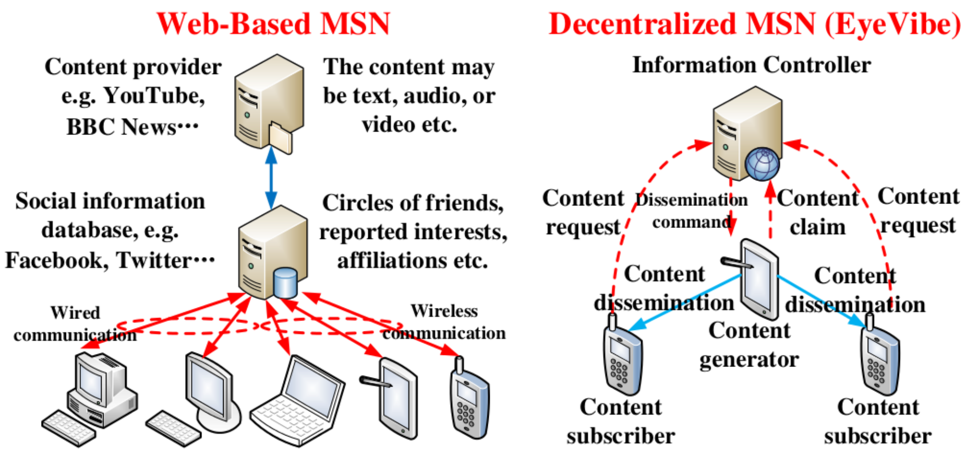


Fig.1 *Two types of mobile social networks*

and virtual social networks, we may significantly enhance their achievable performance by exploiting the characteristics of the mobile users' social relationships and behaviours.

In this article, we firstly overview the architecture of MSNs in Section II, while in Section III we propose a MSN aided content dissemination scheme and survey a range of factors, which may affect the performance of the content dissemination process. In Section IV, we present a case study of MSN aided content dissemination in the context of cellular communications, while a range of other applications are introduced in Section V. After outlining a range of future challenges in Section VI, we offer our conclusions in Section VII.

II. THE ARCHITECTURES OF MOBILE SOCIAL NETWORKS

In MSNs, a client is redefined as a group of mobile users, who form a community, instead of a single mobile user. In MSNs, the following factors distinguish one community from another: the number of members, the geographic area covered by a community, their social relationships, and mobility patterns as well as the various wireless techniques (e.g., WIFI or Bluetooth) adopted for information dissemination, etc. Below we first survey two types of MSN architectures.

2.1 Centralized mobile social networks

In the centralized MSN [2], as shown at the left of Fig.1, when a MSN user *A* wants to share a video clip with his/her friend *B*, user *A* first logs onto a social networking website and posts a link of this video, which leads users to the server of the content provider. Then the social networking service delivers a notification to user *B*. After logging onto the social networking service, user *B* would find the link and would acquire the content from the server of the content provider by clicking on the link.

Hence, the social networking services play an important role in connecting the users to the content providers and in carrying out content dissemination more efficiently. The structure of the social communities may be deemed to be relatively stable, unless the MSN users change their preferences or friendship ties over time. Since all the social profiles are updated by the users themselves, it saves efforts in defining social relationships and in discovering the structure of communities. However, since all the communications are conducted through centralized servers, there are no direct interactions between users *A* and *B*. As a result, the centralized MSN architecture is unable to offload the traffic burden imposed on the network operators.

2.2 Decentralized mobile social networks

In a decentralized MSN [2], as shown at the right of Fig.1, after recording a video clip, a MSN user (content generator) sends a message to the information controller to claim the authorship of the video clip. After receiving this message, the information controller broadcasts it to all of the MSN users. Any MSN users (subscribers), who are interested in the video, report their interests to the information controller. By synthesizing all the information collected from the subscribers, a temporary community can be established, which includes both the content generator and all the subscribers. Then, the constitution of the community is broadcast to all its members. As a result, an ad hoc network is created by self-organization, based on which the content dissemination from the content generator to the subscribers can be seamlessly carried out. Finally, once the content dissemination has been completed, the community may be dismissed.

Since content dissemination across the community is self-organized by the MSN users themselves, this MSN architecture is capable of reducing the data traffic tunnelled through the BS-aided architecture of wireless network operators. As a result, in the next section, we will propose a content dissemination scheme for decentralized MSNs and survey the relevant factors, which may affect the content dissemination performance.

II. CONTENT DISSEMINATION

By mimicking the Twitter users' behaviour, we propose a content dissemination scheme based on the common interests of the MSN users supported by decentralized MSNs. All of the MSN users act both as receivers and transmitters. Initially, some of the MSN users receive the desired content from a centralized infrastructure or generate the content themselves. Then, they broadcast (like 'tweet') the content to all the others who have not received it. Due to the variability of the associated wireless links, some of the users may successfully receive the content, while others may not. The users who have successfully received the content from their friends will join the group of transmitters and broadcast the content further (like 'retweet'). In this way, more and more users will join the group of transmitters, until all of the MSN users obtain the desired content.

In decentralized MSNs, the content may be delivered from a content owner to a content receiver, when the following two events occur simultaneously: (1) The content owner has a social relationship with the content receiver, which indicates that there is a social link connecting them in their virtual social networks; (2) The content receiver is within the transmission range of the content owner, which indicates that there is a wireless link connecting them in a physical ad hoc network.

In some previous contributions, such as [3], the goal of "content dissemination" is to deliver the content from a specific source to a specific target. However, in our paper, the purpose of content dissemination is to distribute the content from a specific group of sources to the entire MSNs. In [4], although an optimal rate allocation scheme is proposed for keeping the content as up-to-date as possible, the authors did not consider the content dissemination delay.

From the perspective of network operators, the goal is to reduce the content dissemination delay, which is the time duration from the start of content dissemination until all the MSN users receive the content of common interest. However, the individual MSN users only tend to be concerned about their own delay of receiving the content. There are a range of factors affecting the content dissemination process, which are elaborated on below.

3.1 Status of MSN users and strength of their relationships

A virtual social network consists of some MSN users and of the corresponding social links connecting them. However, the MSN users exhibit different social status in the virtual social networks. Furthermore, the strength of social links varies from one pair of MSN users to another. Let us now present the methods of evaluating the MSN users' social status and the strength of their social links.

Firstly, the concept of centrality [5] defined in graph theory may be exploited for describing the social status of MSN users, yielding the concepts of degree, betweenness and closeness. The degree $C_D(i)$ of node i is defined as the total number of social links connected to this node in virtual social networks, as shown in Fig.2(a). The node associated with a higher degree has more neighbours. For example, the degree of node 1 is seen to be $C_D(1)$=6. The betweenness $C_B(i)$

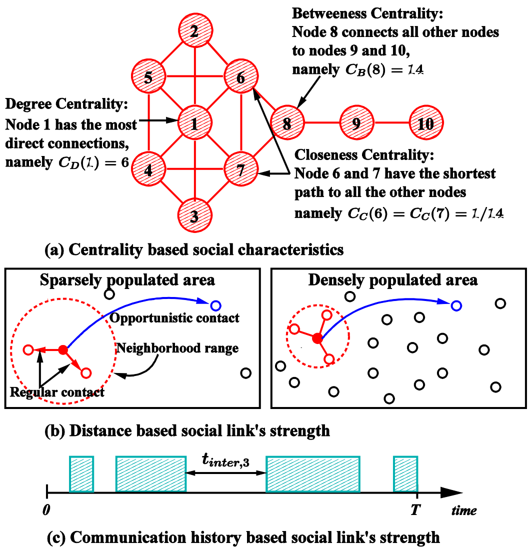


Fig.2 *Defining social relationships*

of a node i is defined as

$$C_B(i) = \sum_{j<k}^{j,k\neq i} g_{jk}(i) / g_{jk}$$

where g_{jk} is the number of the shortest paths connecting nodes j and k, while $g_{jk}(i)$ is the specific number of these shortest paths passing through node i. The node having a higher betweenness is acting as a bridge node connecting two different components of the graph, as shown in Fig.2(a). For example, the betweenness of node 8 is seen to be $C_B(8) = 14$, as shown by Note 1. Finally, the closeness $C_C(i)$ of node i is defined as

$$C_C(i) = \left[\sum_j d(i,j)\right]^{-1}$$

where $d(i,j)$ is the number of hops of the shortest path between node i and node j. The node associated with a higher closeness has a fewer number of hops from all the other nodes on average as shown in Fig.2(a). For example, the closeness of node 6 (or node 7) is seen to be $C_C(6) = C_C(7) = 1/14$, as shown by Note 2.

Secondly, there are two ways of describing the strength of social links. The social links are often related to the geographic distances [6] between the MSN users, as shown in Fig.2(b), which are characterized by the so-called neighbourhood range. If there are any other MSN users located within the neighbourhood range of MSN user A, they tend to have more regular interactions with user A. Hence they may be referred to as the regular contacts of user A. Apart from the regular contacts, a MSN user is likely to have certain contacts with the MSN users outside the above-mentioned neighbourhood. These MSN users are hence termed as the opportunistic contacts. The probability of an opportunistic social link between two MSN users is usually modelled by an inverse-power law based decay with their geographic distance [7]. Moreover, the neighbourhood range depends on the MSN users' density. In realistic scenarios, a higher user density always results in a shorter neighbourhood range, as shown in Fig.2(b).

Apart from the above-mentioned geography based description, the strength of social links connecting two MSN users is also derived from their communication history, as shown in Fig.2(c), where the shaded blocks denote their contact period. Numerous metrics were proposed for describing the social relationships between two users, including the average separation period, the total or average contact period, as well as the relative frequency of contacts. For overcoming partialities of the above metrics, the authors of [8] have proposed a simple but effective way of incorporating all of the features of the above metrics. This was achieved by defining the strength of the social link between the MSN users i and j as

$$w_{i,j} = (2T) \Big/ \left(\sum_{x=1}^{n} t_{inter,x}^2 \right)$$

where $t_{inter,x}$ is the xth separation period during the observation period T as shown in Fig.2(c).

3.2 Human behaviours

Typically, two types of human behaviours have to be considered, namely the human altruism [9] and social mobility patterns.

In content dissemination, after receiving the content from others, a MSN user has to consume some of his/her handset's power to forward it. As a result, the MSN user may be hesitant to continue disseminating the content to others. For simplicity, we denote the probability of a MSN user willing to disseminate the content in the community as q, which we term as the factor of altruism (FA). According to our intuition, a higher value of FA implies that the MSN users become more altruistic as well as that more MSN users are willing to share the content with each other during content dissemination. Hence, the content dissemination delay may be reduced, as shown in Fig.5(a) of Section 4.3.

Another factor is the mobility pattern of the MSN users. In an intermittent ad hoc network, the content can be successfully delivered, if the content receiver enters the content owner's transmission range. Moreover, in a well connected ad hoc network, the channel's path-loss is determined by the distance between the content owner and receiver. As a result, the content dissemination is substantially affected by the MSN users' mobility pattern. Explicitly, conventional analytical mobility models, such as the random walk model [10], the random direction model [10], the random waypoint model [10], and the Gauss-Markov model [10] etc, may not closely reflect the typical human social behaviours. For the sake of addressing this modelling deficiency, a community based mobility model has been proposed in [11]. The trace of a MSN user consists of several epochs, where every epoch obeys the principle of any of the above-mentioned analytical mobility model. In community based mobility model, there are two states for any epoch of a MSN user, namely the locally bounded epoch and the wide area roaming epoch. When a MSN user moves along a local epoch, his/her mobility is bounded by his/her local community. By contrast, when a MSN user moves along a roaming epoch, he/she may travel anywhere in the entire area. The stochastic properties of the community based mobility model still require further studies.

3.3 Scale of mobile social networks

According to their sizes, MSNs can be divided into two different categories, namely small-scale MSNs and large scale MSNs. The size of a large-scale MSN may be much larger than the transmission range of a mobile device. Provided that communication may only occur when a target user enters a source user's transmission range, the content dissemination delay will mainly rely on the mobility pattern of MSN users. Since the inter-encounter time between two MSN users may last for several minutes, hours, or even days, content dissemination may have to tolerate a delay in delivering the content to all the MSN users, which might be of the same order. Hence, large-scale MSNs belong to the class of delay tolerant networks (DTNs) [12].

By contrast, the size of a small-scale MSN is small compared to the transmission range of a mobile device. In a small-scale MSN, regardless where the content owner is, he/she is always capable of delivering the content to the hitherto unserved users, provided that they are in his/her friendship list. As a result, the content dissemination delay between two users is determined by the characteristics of the wireless link connecting them. Hence, the content dissemination delay is on the order of a time slot’s duration, which is usually quantified in milliseconds.

3.4 Protocol designs

In order to avoid transmitting multiple copies of a content to a MSN user, it is important to inform the source node of whether or not his/her friends in the transmission range have received the content.

By adapting Sensor Protocols for Information via Negotiation (SPIN) [13], our content dissemination protocol may be divided into two parts based on the content owner's perspective and the content receiver's perspective, as shown in Fig.3, where the filled nodes represent the users who have received the content, while the unfilled nodes represent those who would like to receive it. Let us first consider the Fig.3(a) portraying the content owner's perspective. The content owner firstly broadcasts an Advertisement (ADV) message to all the other nodes located in his/her transmission range for claiming the ownership of the content. If the MSN users would like to receive the content, then Request (REQ) messages are returned to the content owner, while the other users, who have already received the content, remain silent. Upon receiving the REQ messages, the content owners would become aware of who are interested in the content. Then, the content is disseminated to the interested MSN users. As a reward, the social credits are awarded to the content owners, making them popular in the social community. A modest revision is required for supporting the scenario, where the source is only able to disseminate its content

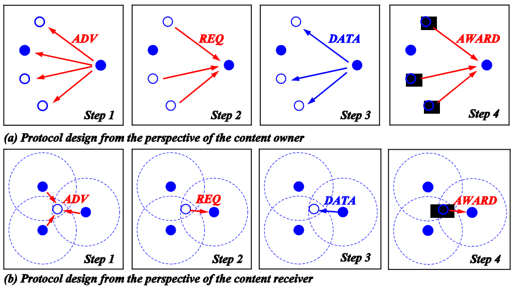


Fig.3 *Protocol designs for content dissemination in MSNs*

to a limited number of targets. We observe at step 2 of Fig.3(a) that all of the targets who are interested in the content will also send information on the amount of social credit they earned, which is contained in the REQ messages. Then the source would select the specific targets who have earned the most social credits. Consequently, this prioritised content-sharing regime may facilitate expedited content dissemination across the whole community.

A MSN user *A* without the content may enter the transmission range of several content owners. If all of these content owners broadcast the content to user *A*, unnecessary contention may occur. In order to avoid contention, we can design a dissemination protocol from the perspective of the receiver, as shown in Fig.3(b). At step 1, user *A* enters the transmission range of three content owners and receives the ADV messages from all of them. Based on the information provided by these ADV messages, user *A* selects one out of the three users to send the REQ message to. This user-selection may be made based on the quality of the links. After receiving the REQ message, the selected content owner will send the content to user *A*. When the content is successfully delivered to user *A*, the correspondingly social credit is granted to the transmitter.

As a benefit of introducing the social credit, the altruistic MSN users would receive the content before the selfish ones. Moreover, the social credit is granted only after the successful dissemination, which circumvents devious user behaviours.

3.5 Theoretical modeling of the content dissemination delay

By defining each state as the number of MSN users who have already received the content, we can model the process of content dissemination as a Pure Birth Markov Chain (PBMC) with an absorption state *N* representing that all the *N* MSN users receive the content. The process of content dissemination may start at any state, depending on the number of MSN users initially obtaining the content. In this PBMC, the state transition probability is determined by the following two factors: the number of links available for connection between the content owners and the content seekers, and the successful content delivery probability of each link. We note again that the existence of a link for delivering the content depends on whether a physical link exists in the ad hoc network considered, and whether a social link exists in the virtual social network.

According to the definition of small-scale MSNs as discussed in Section III-C, the physical ad hoc network constructed by MSN users forms a fully connected graph, where a physical link exists between any pair of nodes. As a result, the number of links available for data dissemination mainly depends on the number of social links between the content owners and content seekers, as well as on the altruistic behaviours of MSN users. However, the probability of successful data dissemination over a specific link is jointly determined by both the physical link's reliability and by the strength of the relevant social link, as well as by the size of the content.

By contrast, according to the definition of large-scale MSNs, as detailed in Section III-C, a MSN user only shares physical links with others who enter his/her transmission range. Hence, the connectivity of the physical ad hoc network constructed by MSN users is determined by the MSN users' mobility pattern. Consequently, the number of links available for data dissemination mainly depends on the specific nature of the non-fully-connected physical ad hoc networks, virtual social networks, as well as on the MSN users' altruistic behaviours. Correspondingly, the probability of a link's successful data dissemination is determined by the rate of two MSN users encountering each other and by the size of the content.

Note that, in practice, if the content is constituted by succinct comments or even if it is more substantial, but a higher bandwidth is available, the transmission delay of the content between a pair of physically connected content owner and content seeker may be ignored, when it is compared to their inter-encounter time. Naturally, the success of content dissemination is conditioned on whether the destination is within the source's transmission range. However, if the content is constituted by large video or audio files, but the bandwidth available for content dissemination is limited, the success of content delivery will depend on the inter-encounter properties of the MSN users, and on the duration of the communication sessions, which must be longer than the transmission duration required for the delivery of the content between a pair of physically connected content owner and receiver.

3.6 MSN aided content dissemina - tion vs conventional Bit - Torrent

Although our MSN aided content dissemination scheme has similar features to those of the conventional BitTorrent (http://www.bittorrent.com/), some major differences are related to the following aspects:

(1) The impact of social relationships is ignored in the conventional BitTorrent, albeit the content of common interest may be more efficiently delivered, if the content owner and content receiver share a social relationship in our scheme;

(2) In the conventional BitTorrent, all communications are via the centralized infrastructure, whilst our content dissemination regime is operated through either a fully connected ad hoc network (for the small-scale MSNs) or an intermittent ad hoc network (for the large-scale MSNs);

(3) In the conventional BitTorrent, users are happy to share their content in order to achieve as high a data rate as possible. However, since they have a limited battery charge and delivery capacity, in our content dissemination scheme the users may be reluctant to share the content with others.

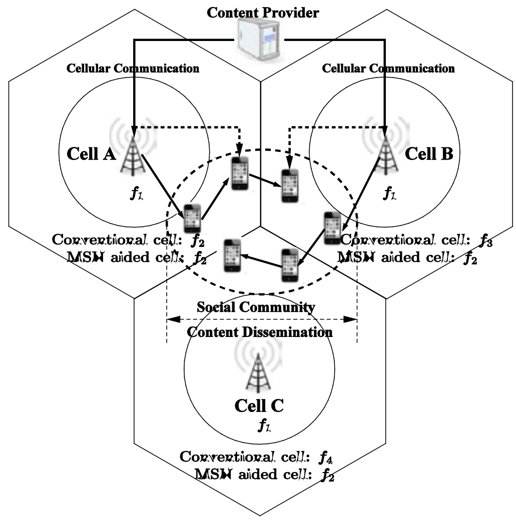


Fig.4 *MSN content dissemination aided cellular communications*

IV. MOBILE SOCIAL NETWORKS AIDED CELLULAR COMMUNICATIONS

In this section, we present an application example of MSN aided content dissemination in cellular communication systems. We demonstrate the advantages of our schemes over conventional wireless networking.

4.1 Motivations

Fractional frequency reuse (FFR) [14] has been conceived for cell-edge interference mitigation, where the frequency bands f_2, f_3 and f_4 are allocated to the cell-edge users of the adjacent cells, while supporting the centre-cell users within the frequency band f_1, as shown in Fig.4. If we assume that the number of cells in a cluster is 3, the frequency reuse factor is in the range of [1/3,1] and the specific value depends on the bandwidth ratio of f_1 to f_2, f_3 and f_4. Naturally, we compensate for the inter-cell interference at the cost of an increased bandwidth requirement. Alternatively, only a reduced bandwidth is available for f_1, f_2, f_3 and f_4, when the total bandwidth of (f_1+ f_2+ f_3+ f_4) is fixed.

Additionally, for the sake of enhancing the coverage-quality of a cell, the BSs have to transmit at an increased power for supporting the cell-edge users. However, this conventional technique of improving coverage contradicts to the power-efficient philosophy of 'green' communications.

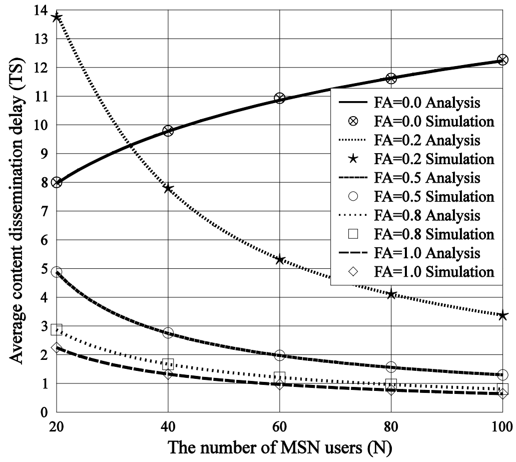
4.2 System overview

In our scheme, the MSN users are divided into two categories, namely active subscribers (ASs) and passive subscribers (PSs), where the ASs initially receive the content from the BSs, while the PSs receive the content from their counterparts during content dissemination. Fig.4 portrays a hybrid MSN architecture, where the content of common interest is generated by the content provider and arrives at the subscribers via the following stages:

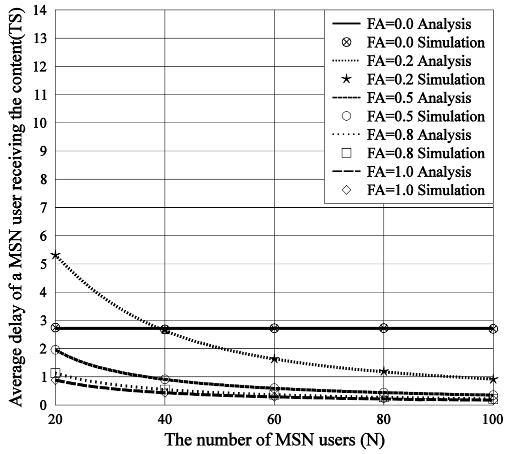
(1) *Cellular communication*: The BSs operating in the frequency band f_1 are employed by the content provider to assist in disseminating the content to *U* ASs.

(2) *Content dissemination*: We assume that there are *N* MSN users in total. After the first-stage of transmission, *U* ASs receive the content from the BSs. Then these ASs further disseminate the content to the other PSs. If a AS/PS receives the content, it assists in disseminating the content to his/her contacts. This dissemination process continues until all the MSN users receive the content.

We study the content dissemination process in the context of a small-scale MSN in a densely populated area. Therefore, according to Section 3.5, the content dissemination can be modelled by a PBMC. This PBMC starts at the initial state *U* and terminates at the absorption state *N*, indicating that all users obtain the content. By jointly considering both the path-loss and Rayleigh fading, we assume that a packet of the content can be successfully received by a content receiver, when the instantaneous signal-to-noise ratio (SNR) at the receiver exceeds a pre-defined threshold. Then, we may derive the probability of successful packet dissemination over a single link. Assuming that the current number of content owners is *k*, as well as assuming the altruistic human behaviour of Section III-B, the number of content owners willing to share the content obeys a Binomial distribution associated with *k* and the FA parameter *q* [15]. Specifically, when there is no content owner willing to share the content, the content receivers have to turn to the BSs for downloading the content. In this scenario, we may analytically derive the content dissemination delay, as detailed in [15].



(a) Content dissemination delay.



(b) Delay of a specific MSN user receiving the content.

Fig.5 *Total delay of the content dissemination and the delay of a specific MSN user receiving the content. (1) Parameters of content dissemination between a BS and the MSN users: transmit power is 17 dBm, carrier frequency is 1.8 GHz, available bandwidth is 100 MHz (these physical layer parameters are in line with LTE-Advanced standard), the average distance is 1.5 km; (2) Parameters of content dissemination amongst the MSN users: transmit power is -30 dBm, carrier frequency is 3 GHz, available bandwidth is 10 MHz, the average distance is 20 m; (3) the SNR threshold of MSN users required for successful content-reception is 10 dB. (4) Half of the MSN users initially receives the content of common interest before the content dissemination.*

4.3 Performance results

As shown in Fig.4, content dissemination may be carried out within the frequency band f_2. Since there is no communication between the PSs and the BSs during this stage, the inter-cell interference is eliminated and only two frequency bands are allocated in the multi-cell environments considered. Hence, the frequency reuse factor is increased from the range of [1/3,1] to the range of [1/2,1].

Moreover, in a frequency division duplex (FDD) system, the MSN-based content dissemination may be beneficially conducted in the UpLink (UL) frequency band near the cell-edge, because this would impose only limited interference on the UL-reception at the BSs. In this scenario, the frequency reuse factor is equal to one. Furthermore, when relying on cognitive radio techniques, content dissemination may be carried out in the spectrum holes of the frequency band f_1, which also results in a frequency reuse factor of unity. Apart from saving bandwidth, content dissemination may also substantially reduce the transmit power of the BSs, since the cell-edge MSN users receive the content not directly from the BSs, but from one another.

Let us now briefly consider the average content dissemination delay and a single user's delay. We should note that in Fig.5 (a)(b), the curves associated with FA=0 present the performance of BS-aided content dissemination relying on conventional broadcasting. Since FA=0 indicates that the content owners are never willing to share the content with others, the BSs have to broadcast the content to the content receivers.

In Fig.5(a), we plot the content dissemination delay against the number of the MSN users, which is affected by the factor of altruistic (FA) detailed in Section III-B. When FA is not zero, the average content dissemination delay, whose unit is time slot (TS), reduces steadily as the number of the MSN users increases. Having more MSN users implies having more potential transmitters during the content dissemination, which results in a substantial reduction of the content dissemination delay. By contrast, having higher FA produces a reduced delay. The reason for this trend is that a higher FA indicates that in every state more MSN users are willing to share the content, which accelerates content dissemination across the MSN. Moreover, we observe a completely reversed trend for FA=0. In this scenario, the MSN users have to turn to the BS for downloading the content, and we only have the BS as our transmitter. Hence, if the number of receivers in the MSN is increased, the delay is also increased. This observation demonstrates that MSN aided content dissemination substantially reduces the delay compared to conventional broadcasting.

In Fig.5 (b), we plot the delay of a specific user receiving the content against the number of the MSN users. The delay is also reduced when the number of the MSN users increases, provided that FA is not zero. However, when FA is zero, the delay remains near-constant as the number of the MSN users increases. Since only the communications between the BS and MSN users are established in this particular situation, the delay of a specific user receiving the content is only determined by the quality of the link connecting this MSN user to the BS.

According to the above results, we can see that when invoking MSN-aided content dissemination in cellular communication, both the overall delay and the delay of a single user are substantially reduced, which makes this design attractive for both network operators and mobile users.

V. OTHER APPLICATIONS OF MOBILE SOCIAL NETWORKS AIDED CONTENT DISSEMINATION

MSN aided content dissemination may find numerous other applications as exemplified below.

1) *Communications in Rural Areas*. In this scenario, MSN users are sparsely distributed in a large area, where there is a paucity of centralized infrastructure. Hence MSN aided content dissemination may be an attractive approach for extending the communication coverage.

2) *Car to Car Communications*. Since motorways often pass through rural areas, it is also beneficial to support car-to-car communication with the aid of MSN assisted content dissemination. A pair of cars may exchange the information of common interest, when they are in each other's vicinity. As a result, important information, such as accidents and traffic jams may be spread promptly along the motorway. These messages may also be used to activate the car's braking system, ultimately leading to the concept of smart cars that simply never crash

3) *Emergency Communications*. During a natural disaster, such as the Tsunami in Japan, most of the communications infrastructure may be destroyed. It is hard for victims to send out SOS messages in conventional ways. Based on the concept of MSN, mobile devices may be used for creating a self-organized ad hoc network, so that SOS messages may be sent. In reality, every user's phone is unaware of the particular nodes that are capable of communicating with the outside world. Our MSN aided content dissemination regime is applicable in this scenario, where SOS messages constitute crucial contents. After generating their SOS messages, the victims flood all the other mobile devices and when the specific node having a link to the outside world via a surviving BS receives it, it forwards the information to the outside universe.

4) *One Laptop Per Child (OLPC) Project*. The charitable goal of the OLPC project is to design and distribute inexpensive laptop computers to children in developing countries around the world, in order to provide them with access to knowledge and opportunities. Based on the common hardware and software platform, it is easy for content providers to provide useful contents of common interest to children, such as educational programs. Our MSN aided content dissemination is also applicable in this scenario for distributing contents, where the children speaking the same languages or the children in the same age-group form a community. However, the transmit power of laptops is limited due to their low-cost design. The major challenge is how many laptops would have to be distributed and what density of users would be required for making content dissemination efficient.

5) Satellite communications. The principle of MSN aided content dissemination may also be useful in the scenario of satellite communications. In a TV broadcast satellite system, the contents of common interest are TV programs, and all the satellites form a community, each of which covers a specific area of the globe. As a result, after a satellite receives the original signal from a TV program distribution earth-station, it can disseminate the content to all of its counterparts. Since the delay is an influential performance factor in TV broadcast systems, the design of low-delay, high-efficiency content dissemination algorithms is of high importance.

VI. FUTURE CHALLENGES

There are still many open issues and challenges in MSN-aided content dissemination.

1) Physical layer improvements. In order to facilitate the practical exploitation of our MSN aided content dissemination regime, physical layer techniques have to be improved further. In a multi-source scenario, it is better for the target to be capable of detecting the information from all the sources. Efficient techniques have to be proposed for minimizing the interference when numerous transmissions are established simultaneously. The employment of sophisticated synchronization technique is also important during content dissemination.

2) Efficient power allocation. This is a crucial issue, since mobile devices are powered by batteries.

3) Modelling of mobility patterns. In real life, a person's mobility pattern often exhibits periodicity. Everyone has regular mobility traces. For example, from 7:00 am to 8:00 am, a person is at home having breakfast; from 8:00am to 9:00 am, he/she is on his/her way to work... and he/she will repeat all these actions in the next day. For studying the achievable content dissemination performance more accurately, a periodic mobility model has to be found and its stochastic properties deserve careful investigations.

4) Optimal strategy design. Our goal is to find an optimal design to make the content dissemination delay as low as possible. There are two ways of designing the optimal strategy. First of all, by carefully selecting the MSN users, who first receive the content according to their social characteristics, which are represented by centrality, namely their degree, betweenness and closeness, we may operate content dissemination more efficient. These investigations require both analytical and simulation results for determining the specific characteristics of those MSN users, who are best suited for content dissemination as the

initial content owners. Again it is plausible that they should have a high degree, high betweenness and high closeness. Secondly, we should find an optimal award mechanism for accelerating content dissemination, while avoiding the fraudulent behaviour.

VII. Conclusions

In this article, we presented the principles of MSN aided content dissemination, where the MSN users rely on self-organization and ad hoc networking for disseminating the desired content across the community. After surveying two basic types of MSNs, we investigated the specific factors, which may affect the performance of content dissemination. Moreover, we proposed an application of MSN aided content dissemination in cellular communications. We demonstrated that network operators may benefit from employing our scheme in densely populated areas, which results in a reduced dissemination delay at the cost of reduced investments. MSN aided content dissemination may also be widely applied in diverse scenarios. However, numerous challenges have to be tackled in this area.

Note

1.
$$
\begin{aligned}
C_B(8) &= \frac{g_{1,9}(8)}{g_{1,9}} + \frac{g_{1,10}(8)}{g_{1,10}} + \frac{g_{2,9}(8)}{g_{2,9}} + \frac{g_{2,10}(8)}{g_{2,10}} + \frac{g_{3,9}(8)}{g_{3,9}} \\
&+ \frac{g_{3,10}(8)}{g_{3,10}} + \frac{g_{4,9}(8)}{g_{4,9}} + \frac{g_{4,10}(8)}{g_{4,10}} + \frac{g_{5,9}(8)}{g_{5,9}} + \frac{g_{5,10}(8)}{g_{5,10}} \\
&+ \frac{g_{6,9}(8)}{g_{6,9}} + \frac{g_{6,1}\ (8)}{g_{6,1}} + \frac{g_{07,9}(8)}{g_{07,9}} + \frac{g_{7,1}\ (8)}{g_{7,1}} \quad {}^{0}_{0} \\
&= \frac{2}{2} + \frac{2}{2} + \frac{1}{1} + \frac{1}{1} + \frac{1}{1} + \frac{1}{1} + \frac{1}{1} + \frac{1}{1} + \frac{1}{1} + \frac{1}{1} + \frac{1}{1} + \frac{1}{1} + \frac{1}{1} + \frac{1}{1} = 14
\end{aligned}
$$

2.
$$
\begin{aligned}
&C_C(6) = 1/(d(6,1) + d(6,2) + d(6,3) + d(6,4) + d(6,5) \\
&+ d(6,6) + d(6,7) + d(6,8) + d(6,9) + d(6,10)) \\
&= 1/(1+1+2+2+1+0+1+1+2+3) = 1/14
\end{aligned}
$$

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A summarized sentence asked by the editor:

"Mobile social network (MSN) aided content dissemination technique is capable of supporting conventional cellular wireless networks in terms of satisfying the increasing data traffic. By allowing the MSN users to create a self-organized ad hoc network for spontaneously disseminating the contents, the network operator may be able to reduce the operational costs and simultaneously achieve an improved network performance."