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MODELLING MOBILE ENCOUNTER NETWORKS

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ABSTRACT

This article presents Mobile Encounter Networks, which emerge when mobile devices come across each other and form a temporary connection between them using a common short-range radio technology. Local information exchanges between mobile devices results in a broadcast diffusion of information to other users of the network with a delay. In addition to presenting the concept of mobile encounter networks, we also provide an abstract method for describing the information diffusion process inside them.

INTRODUCTION

Mobile Peer-to-Peer (MP2P) networks are designed for resource sharing in mobile environments. These networks include structureless ad hoc networks as well as infrastructure based cellular networks with terminals having capabilities to share their resources. There are various examples of peer-to-peer applications for ad hoc networks [8],[3],[14],[6], cellular networks [10],[1] or both [4].

Resource sharing in general can be described from two different approaches. First, we can look at the way the resources are processed: the resources can be shared proactively, which means providing peers with them without a specific request, or reactively which means sharing resources on demand. The second approach is to study the way the resources are transmitted from the provider-peer to the user-peer. In multi-hop transmission, the resources are delivered via other intermediate peers, whereas single-hop transmission allows communication only between adjacent nodes.

These two approaches are presented in table 1. Because this paper focuses on information transmission, the table concentrates on this feature. However, the same categorization could also be used with different resource types.

Both of the routing methods, proactive and reactive, are applicable in the context of mobile peer-to-peer networks, however, proactive transmission of the routing information will cause substantial overhead compared to payload traffic. The reason for that comes from the fact that the mobility of network nodes continuously changes the topology of the network, and thus, routes between network nodes must be updated frequently, and this new information must be delivered to all the nodes whether or not they benefit from it. Thus, proactive routing information transmission is better suited for systems that are rather stable, such as routing in a wired network. Reactive request of the routing information, on the other hand, is best used in a dynamic environment, such as a mobile ad hoc network. When a route between communicating network nodes is requested only when it is actually required, unnecessary data transmissions are avoided.

Table 1: Information diffusion in different environments.

Communication Method	Transmission type: Single-hop	Transmission type: Multi-hop
Reactive	Query from a known information source	Mobile ad hoc network routing
Proactive	Data exchange with other mobile peers	Routing in a wired network

The both routing examples mentioned above share a common feature: the message is transmitted via other network nodes. This is, indeed, the only way to deliver a message from node to node with no direct data link between them. In MP2P, however, the network topology changes as mobile nodes move. Due to these changes, the nodes may end up near another node which possesses desired information or to which they want to deliver information. This whole system is simplified by allowing only direct links so that information is transmitted from the source node to the target without intermediate nodes. Therefore the only remaining option is to proactively query the required data from the nodes it encounters.

This paper introduces a new class of mobile networking systems, the mobile encounter networks. These networks do not require an infrastructure and do not have problems of multi-hop communication requiring much lower density of mobile devices compared to ad hoc networks for operation. There are, however, certain limitations of applications operating in mobile encounter networks, but some applications are feasible to be built using mobile encounter network architecture.

The paper is structured as follows. Section II introduces related work in the area of mobile peer-to-peer networks, information diffusion in mobile environments and delay-tolerant networking. Section III provides an overview of the mobile encounter network concept and compares it with ad hoc networking. Section IV introduces an abstract model for describing data sharing in mobile encounter networks. Section V concludes the results.

RELATED WORK

Mobile encounter networks and MP2P systems both reside on the application layer relying on short range wireless technology for communication inside encounters. However,

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there are some characteristics, which distinguish mobile encounter networks from other MP2P systems. Multi-hop resource discovery commonly found in P2P systems is missing from mobile encounter networks. Resource discovery in mobile encounter networks is done via pair-wise communication between two mobile devices inside an encounter and does not involve other devices outside the encounter. The way of obtaining data in mobile encounter networks is push-based rather than pull-based commonly found in other MP2P systems [11]. Mobile encounter networks are not intended for searching, but rather for spreading information to interested parties.

Information diffusion in mobile encounter networks takes place when a mobile device stores information obtained from another mobile device in an earlier encounter and later forwards the information to other mobile devices in new encounters. The diffusion of information in such a network is delayed and represents a way of replicating information lazily among the devices. The origin of the information diffused in mobile encounter networks can be any external source, e.g. user or device.

The devices participating in the mobile information diffusion need to provide some resources for the diffusion process. For example, transmitting information always requires some amount of battery power and therefore some part of the information diffused in the mobile encounter network needs to be relevant for the user of the device. Information diffusion in mobile communities has been studied by e.g. [9],[11].

As was mentioned earlier, mobile encounter networks are slow in spreading data. In certain application scenarios, however, the slow speed of information transmission, does not present a problem. Communication systems of this type are referred to as delay tolerant networks (DTN), and have been the subject of interest in different contexts. In these studies [7],[13], entities which are already in motion have been used to transport information.

Mobile encounter networks combine the concepts of MP2P and DTN while providing the tools for modelling information diffusion.

Mobile Encounter Networks

Mobile encounter networks are formed of mobile devices coming across each other and having a connection between them using short-range radio technology, such as Bluetooth or WiFi. One encounter contains the discovery of devices, the establishment of connection between two devices and the exchange of data. One mobile device can form connections to multiple other devices in succession. In this way, the information from one node can be copied to many other mobile devices. The duration of the encounter is usually short, because of the mobility of the devices, but it can also be long if the mobile devices are not moving or have similar motion patterns. A mobile encounter network is then the network resulting from all encounters. Mobile encounter networks are very dynamic, and in contrast to ad hoc networks, they do not provide continuous multi-hop communication, but only a successive pair-wise communication between two mobile devices.

Compared to infostations [5], mobile encounter networks provide faster diffusion of information, because the mobile devices can obtain information not only from the infostation, but also from other devices.

In infrastructure based information diffusion, for example in a GSM network, the network is used to transmit information from a mobile device to a centralized server and mobile devices use this centralized server to obtain data. Compared to infrastructure based information diffusion, mobile encounter networks often provide a slower information diffusion and limited coverage. This is because the information is only available to the mobile devices, which have encountered other mobile devices providing the information. However, there are certain advantages in information diffusion over mobile encounter networks. First, there is no need for infrastructure for transmission of data. Second, the information diffusion in mobile encounter networks is inexpensive, because no external service provider is needed for the transmission of data. Also, because all communication takes place within encounters between two mobile devices, there is no need for an external server where information would be stored. Without an external server, which potentially could become a bottleneck in a growing system, the mobile encounter networks are also very scalable.

Mobile encounter networks resemble ad hoc networks in the sense that they allow two mobile nodes that come within range of each other to establish a connection and exchange data. There are, however, many differences between mobile encounter networks and what is usually considered as ad hoc networking.

Perkins [12] suggests that the main problems in ad hoc networks is providing multihop routing of data through the mobile nodes which are potentially moving and continuously changing the configuration of the network. A route in an ad hoc network can be repetitively broken due to a node in its path moving out of the reach of its neighbours. A significant research effort is put into designing algorithms for repairing broken routes without generating too much control traffic. Moreover, routing requires assigning global addresses to the nodes, since the data sent by a source node is targeted at a specific destination node (or possibly at a multicast group), which is not necessarily within the transmission range of the source. Of course multi-hop routing in ad hoc networks considerable extends reachability and decreases the latency, whereas in mobile encounter networks reachability is limited and latency grows when density and mobility of mobile devices decrease.

Compared to ad hoc networks, mobile encounter networks differ in that they do not provide any routing facilities, since the goal is to spread information to as many nodes as possible rather than target specific destinations: a source node running one given application over a mobile encounter network sends data to any other node running the same application entering its transmission range. The other node will cache the data, and later send it further when it comes within range of other nodes. There is no need for mechanisms preventing data to loop back to its original source as in many ad hoc networks protocols. Moreover, since the data is sent only to the neighbours which are within the transmission range, no global addressing is required: The underlying communication medium takes care of assigning addresses to the nodes which are within range of each other since the actual data transmission requires distinguishing different neighbours. In particular, mobile encounter networks do not require the functionalities commonly found on the network layer of protocol stacks whereas the scope of ad hoc networks is mainly on the network layer. Mobile encounter networks operate on application layer and require only link layer connectivity using some wireless radio technology and reliable data transport functionality from the transport layer.

MODELLING MOBILE ENCOUNTER NETWORKS

Next, we will introduce a formal method for modelling the information diffusion process in mobile encounter networks. Let us define B as a vector which maintains the state of n network nodes: whether they possess the information or not.

$$B = [b_1, b_2 \ldots b_n] \quad (1)$$

$$b_i \in \{0,1\} \forall i \in \{1,2,\ldots n\}$$

Further, let us define a matrix

$$F = \begin{bmatrix} f_{1,1}(t) & \cdots & f_{1,n}(t) \\ \vdots & \ddots & \vdots \\ f_{n,1}(t) & \cdots & f_{n,n}(t) \end{bmatrix} \quad (2)$$

to indicate the possibility of nodes communicating with each other so that value 1 of the discrete and binary-valued function

$$f_{i,j}(t) \in [0,1] \quad (3)$$

represents the possibility of communication from node i to node j. Because communication with oneself does not provide added value, let us define

$$f_{i,i} \equiv 0 \forall i \in [1,2,\ldots n] \quad (4)$$

Therefore, we can say that information diffusion taking place at the time t will cause a change in vector B, so that

$$b_i(t+1) = b_i(t) \bigvee_{j=1}^{n} \left[f(t)_{i,j} \wedge b_{j(t)} \right], \quad (5)$$

$$\forall i \in [1,2,\ldots n]$$

Thus we can write

$$\tilde{B} = B \times F, \quad (6)$$

$$b_i(t+1) = \begin{cases} 0, \tilde{B}_i = 0 \\ 1, \tilde{B}_i > 0 \end{cases} \forall i \in [1,2,\ldots n]$$

A set of functions (3), which are elements in matrix F, characterizes the information diffusion process of the mobile encounter networks. Matrix F has a crucial importance in modelling encounter networks, since it contains the information when individual mobile nodes encounter each other. It is important to define the matrix as a function of time, because encounter networks are highly unstable and the data links in them are continuously formed and broken.

In order to find out how F should be defined, we programmed a simulator with Matlab. Our approach was to use the City Block [2] mobility model as a starting point, because it provides a rather realistic model of the behaviour of mobile node entities. We then added two features based on [9] to this model: First, in addition to the information only being copied in the population, it can also be obtained from outside the system. Second, unlike in the original City Block model, in our version the mobile nodes were able to leave the City Block observation area for short periods of time, but they always re-entered the area.

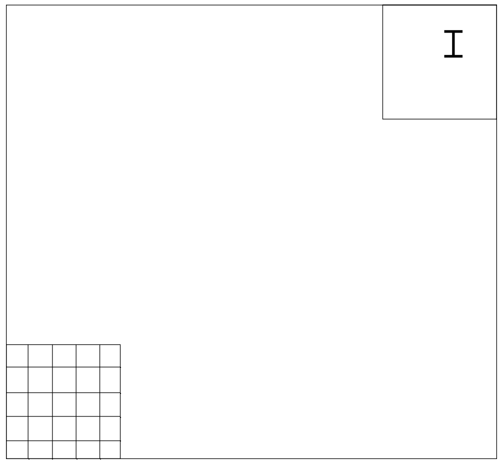

Figure 1. The simulation space.

Figure 1 introduces the simulation space. The City Block is situated in the lower left corner. Every time a mobile node chooses its next target point, there is a 90 % probability that the point will be in the City Block area and a 10 % probability that it will be outside it. This also applies for nodes that are already outside the City Block area. In the upper right corner (I), an information source is located. When a mobile node leaves the City Block area, it may end up in the information source, in which case it receives information. If it does not hit this area, the probability for it to encounter another node is very small, and therefore it is virtually unable to receive information.

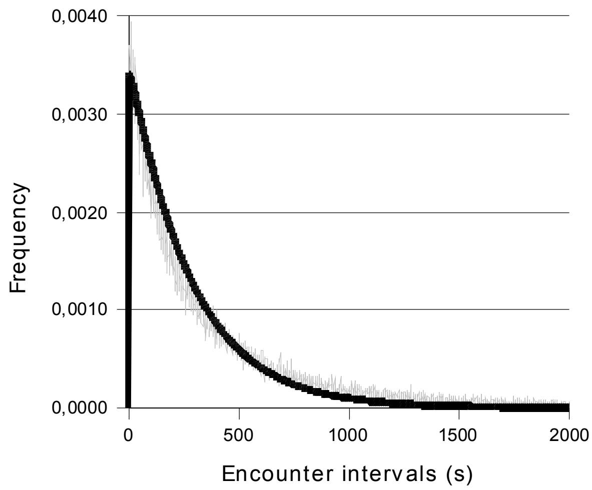

Figure 2. The simulation space.

The simulation model was highly simplified, but since its sole purpose was to study the intervals of node encounters, it was sufficient for our use. Let us say that node A encounters node B at time t_0 and node C at t_1. The interval between those two encounters is thus t_1-t_0. By monitoring all the encounters during the simulation run and comparing the moment of each encounter with the moment of the previous encounter experienced by the same node, we were able to plot a distribution of the encounter intervals.

Figure 2 presents two curves: the average distribution from ten simulation runs and the gamma distribution,

$$g(x) = \frac{\lambda e^{-\lambda x} (\lambda x)^{n-1}}{\Gamma(n)} \tag{7}$$

which the simulation results resemble. Since gamma distribution gives us the time one has to wait until a certain number of events has occurred, its application area is similar to our problem, and therefore we can use it as an example when defining the matrix *F*. In general form function (6) provides insight into the information diffusion process. As it was mentioned above, defining the matrix *F* characterizes the nature of the diffusion process. Our simulation results lead us to believe that when observing phenomena that can be modelled with the City Block mobility model, the nature of the matrix *F* should be defined based on the gamma distribution: The time intervals during which function (3) receives values other than 0 follow the gamma distribution. Let us define that

$$t_{k,i,j} \tag{8}$$

is the time when node i encounters node j for the k^{th} time. Thus we can say that function (3) is defined as follows

$$f_{i,j}(t) = \begin{cases} 1, t \in T = \{t_{1,i,j}, t_{2,i,j}, \ldots t_{k,i,j}, \ldots\} \\ 0, t \notin T \end{cases} \tag{9}$$

and that the values of functions

$$\tau_{i,j}(l) = t_{l,i,j} - t_{l-1,i,j}, l \in \{2,3,\ldots\} \tag{10}$$
$$\forall i, j \in \{1,2,\ldots n\} \wedge i \neq j$$

follow the gamma distribution (7).

Conclusions and Future Work

Mobile encounter networks are emerging as a new area of mobile communication, because of the wide-spread use of short-range radio technologies in today's mobile devices. Some applications are well suited for mobile encounter networks, which are restricted to only single-hop communication. Compared to ad hoc networks, simpler algorithms can be used, and compared to cellular network based MP2P applications, no infrastructure is needed.

It should be noted that there is no method for routing in a traditional sense in mobile encounter networks. Instead, the information spreads through a diffusion process. Therefore, the only layers needed in the protocol stack of a mobile encounter network are physical, data link, transport and application layer. There is no use for a network layer, so it can be omitted.

In this paper we introduced a formal method for describing the information diffusion process and used the City Block mobility model for estimating node behaviour in order to illustrate the characteristics of the formal method. By observing node encounters, we were able to define an applicable form for describing the matrix F, which we had first presented in a general form.

In the future, more simulations should be run with different mobility models, in order to find more function sets for describing different types of application scenarios.

References

[1] Andersen F.-U., de Meer H., Dedinski I., Kappler C., Mader A., Oberender J. and Tutschku K., "An Architecture Concept for Mobile P2P File Sharing Services," Workshop Proc. of Informatik 2004 - Algorithms and Protocols for Efficient Peer-to-Peer Applications, pp. 229-233, 2004.

[2] Camp,T., Boleng, J. and Davies, V., "A survey of mobility models for ad hoc network research", Wireless Comm. and Mobile Computing (WCMC), 2(5):483-502, 2002.

[3] Ding G. and Bhargava B., "Peer-to-peer File-sharing over Mobile Ad hoc Networks," Proc. of IEEE Annual Conference on Pervasive Computing and Communications Workshops, pp. 104-109, March 2004.

[4] Garg N., Shao Y., Ziskind E., Sobti S., Zheng F., Lai J., Krishnamurthy A. and Wand R., "A Peer-to-Peer Mobile Storage System," Technical Report, TR-664-02, Computer Science Department, Princeton University, October 2002.

[5] Goodman D., Borras J., Mandayam N. and Yates R., "INFOSTATIONS: A New System Model for Data and Messaging Services," Proc. of the IEEE Vehicular Technology Conference '97, vol. 2, pp. 969-973, Phoenix, AZ, May 1997.

[6] Helal S., Desai N., Verma V. and Lee C., Konark., "A Service Discovery and Delivery Protocol for Ad-Hoc Networks," Proc. of the IEEE Wireless Communication and Networking Conference (WCNC 2002), New Orleans, LA, March 2003.

[7] Jain S., Fall K. and Patra R., "Routing in a Delay Tolerant Networking," Proc. of the ACM SIGCOMM 2004, Portland, Oregon, August 2004.

[8] Klemm A., Lindemann C. and Waldhorst O., "A Special-Purpose Peer-to-Peer File Sharing System for Mobile Ad Hoc Networks," Proc. of IEEE Semiannual Vehicular Technology Conference (VTC2003-Fall), Orlando, FL, October 2003.

[9] Kurhinen J. and Vuori J., "Information Diffusion in a Single-Hop Mobile Peer-to-Peer Network," Proc. of the 10th IEEE Symposium on Computers and Communications, ISCC 2005, Cartagena, Spain, 2005.

[10] Marossy K., Csucs G., Bakos B., Farkas L. and Nurminen J. "Peer-to-peer content sharing in wireless networks," 15th IEEE Intl. Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC 2004). Vol. 1, pp. 109-114. 5-8 Sept. 2004.

[11] Papadopouli M. and Schulzrinne H., "Effects of power conservation, wireless coverage and cooperation on data dissemination among mobile devices," Proc. of the 2nd ACM Intl. symposium on Mobile ad hoc networking & computing (MobiHoc 2001), Long Beach, California, October 4-5, 2001.

[12] Perkins C., editor. "Ad Hoc Networking," Addison-Wesley, 2001.

[13] Shah R., Roy S., Jain S. and Brunette W., "Data MULEs: modeling a three-tier architecture for sparse sensor networks," Proc. of the First IEEE Intl. Workshop on Sensor Network Protocols and Applications, 2003.

[14] Xue G.-T., Li M.-L., Deng Q.-N. and You J.-Y., "Stable Group Model in Mobile Peer-to-Peer Media Streaming System," The 1st IEEE Intl. Conference on Mobile Ad-hoc and Sensor Systems, October 24-27, 2004, Fort Lauderdale, Florida, USA.