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Design and Analysis Of An Information Sharing System for Human Networks

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Abstract—With fast-growing consumer demands and rapidly-developing mobile technologies, portable mobile devices are becoming a necessity of our daily lives. However, existing mobile devices rely on the wireless infrastructure to access Internet services provided by central application providers. This architecture is inefficient in many situations and also does not utilize abundant interdevice communication opportunities in many scenarios. This paper proposes the human network (HUNET), a network architecture that enables information sharing between mobile devices through direct interdevice communication. We design B-SUB, an interest-driven information sharing system for HUNETs. In B-SUB, content and user interests are described by tags, which are human-readable strings that are designated by users. An experiment is performed to demonstrate the effectiveness of this tag-based content description method. To facilitate efficient data dissemination, we invent the Temporal Counting Bloom filter (TCBF) to encode tags, which also reduces the overhead of content routing. Comprehensive theoretical analyses on the parameter tuning of B-SUB are presented and verify B-**SUB's ability to work efficiently under various network conditio**ns. We then extend B-**SUB's routing scheme to provide a stronger privacy guarantee. Extensive real-**world trace-driven simulations are performed to evaluate the performance of B-SUB, and the results demonstrate its efficiency and usefulness.

Index Terms—Content-based publish/subscribe, interest-driven information sharing, human network, bloom filter

1 INTRODUCTION

WITH fast-growing consumer demands and the rapid development of wireless technology, mobile devices are becoming an indispensable part of our daily lives.Existing wireless networking technologies only allow mobile devices to communicate with each other through wireless infrastructures, for example, GSM/3G/LTE, and so on. This architecture, however, is not ubiquitously applicable. First, it fails in many situations due to limited network resources. For example, in a conference room, the WiFi and cellular connection can be crippled because too many users are competing for the channel simultaneously. Second, this architecture does not take advantage of the abundant interdevice communication opportunities. Again, take the conference room scenario as an example; because of the high density of wireless devices, there can be excellent wireless connections between nearby mobile devices. Existing wireless networks are unable to utilize such communication opportunities.

As a result, this architecture fails to address novel application requirements. Nowadays, most mobile applica-tions are for information sharing; mobile devices are increasingly becoming the end points of information consuming. Evidence is that almost all existing smart phones and tablets are integrated with vendor-supplied music/video streaming services, and social-network-based information sharing services are extremely popular on

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mobile devices. Given the existing architecture, however, they have to connect with central service providers, which would fail in many situations as described above. Besides, this architecture can be inefficient in many scenarios. For instance, location-based chatting is more natural to imple-ment in a peer-to-peer manner, so that nearby users can talk to each other directly.

Recently, a new architecture of networking portable wireless devices has emerged, which is called the delay tolerant networks **(DTNs) [1]. DTNs adopt a “store**-carry-and-**forward”** model, which significantly expands the communication capability of mobile device. Driven by the new application demands and the limitations of the existing architecture, we envision a new type of dynamic network-ing service called human networks (HUNETs). Physically, a HUNET is composed of human-carried mobile devices, which have the same structure as DTNs. These devices use short-range wireless communication technologies, such as WiFi or BlueTooth, to communicate with each other.

Functionally, HUNETs enable information sharing between users in a completely decentralized manner without the aid of an wireless communication infrastructure. A high-level illustration of this architecture is presented in Fig. 1. The figure shows a HUNET composed of four users, each of which carries a mobile device. Users share information they are interested in with nearby peers through direct inter-device wireless communication.

We present B-SUB, an interest-driven information sharing system for HUNETs, which stands for the bloom-filter-based publish/SUBscribe. B-SUB is designed for small to medium sized networks composed of dozens of devices restricted in a limited physical area where interdevice communication opportunities are abundant. Typical application scenarios are researchers inside a conference room, students inside a department building,

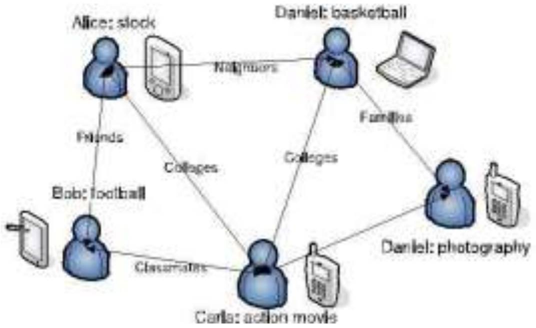


Fig. 1. A high-level illustration of the HUNET. Every user is equipped with a mobile device. Every user has his/her own interests, which is represented as a name:interest pair. Messages are forwarded between users via (multihop) store-carry-forward guided by the user interests.

visitors in a recreation center, and so on. The distinctive features of B-SUB are as follows: First, B-SUB employs content-based networking [2], [3] to achieve infrastructure-less communication. B-SUB routes and forward messages based on their content instead of addresses, which enables autonomous access to interested information for users without an end-to-end addressing mechanism. Second, B-SUB is much more efficient than traditional content-based publish/subscribe. Mobile devices have weak processors and are powered by batteries. Their computational capability is rather limited. Additionally, the memory capacity and bandwidth of the nodes in a HUNET are also scarce. Traditional content-based net-working systems [4], however, are complex and consume excessive memory and bandwidth.

B-SUB employs a tag-based content description model and uses Bloom filters [5] to compress content and user interests. We invent the Temporal Counting Bloom filter (TCBF), an extension of the Bloom filter, to encode tags, which achieves efficient content routing. However, the TCBF has false positives in their queries, which causes useless messages to be forwarded to nodes that are not really interested in their content. We analyze, in theory, several parameters that are related to the false positive probability of the TCBF and their impacts on B-**SUB’s** performance. The analysis is verified through extensive simulation studies. To summarize, our contributions in this paper are as follows:

. We propose HUNET, a novel network architecture that facilitates efficient information sharing between portable mobile devices.

. We design B-SUB, an interest-driven information sharing system for HUNETs, a content-based publish/subscribe that achieves infrastructure-less communication between mobile devices.

- We invent the TCBF, an extension to the counting Bloom filter.
- We conduct extensive theoretical analyses and real-world trace-driven simulations to evaluate the performance of B-SUB.

The remainder of this paper is organized as follows: Section 2 presents the architecture of HUNET. Section 3 introduces the TCBF. Section 4 presents the design of B-SUB. Section 5 analyzes the impact of the parameters of B-SUB on its performance. Section 6 discusses the simulation results.
Section 7 summarizes the relevant work. Conclusion is given in Section 8.

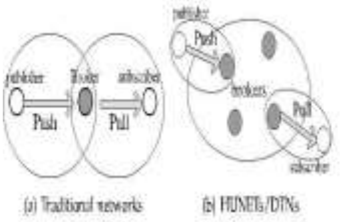
2 THE ARCHITECTURE OF HUNET

The objective of HUNET, as its name suggests, is to facilitate efficient information sharing between humans using mobile devices. A HUNET is composed of portable devices that are equipped with wireless communication interfaces, like WiFi or BlueTooth. Constrained by the relatively weak capability, these devices can only do short-range communication. Advanced wireless communication technologies, like direc-tional antenna [6] could be used to expand the communica-tion range. These devices are always carried and operated by human users, which gives the name of Human Network. They are collectively referred to as nodes in this paper. It is desirable to have non-human-**operated devices to serve as "hot spots" or "offloading stations"** [7] to boost the performance, but is not mandatory. In this paper, we assume that there are no such devices in HUNETs.

The processing power of HUNET nodes is weak. Additionally, because battery is the sole energy source, efficiency becomes even more crucial in HUNET, which is an important driving factor of B-**SUB's design. Users join a HUNET for** sharing information that they receive from others or gather from elsewhere. The most important characteristic of HUNET compared to DTNs is that HUNET exclusively relies on peer-to-peer communication to do forwarding. DTNs, on the contrary, still focus on delivering messages from a source to a destination, although there are generally no end-to-end paths connecting them.

Although HUNETs embody the same network structure as DTNs, DTN routing protocols cannot be directly applied because: 1) DTNs do not support interest-driven commu-nication; 2) DTN routing is based on the end-to-end model, which is not applicable in HUNETs because the information source is unaware of the users who are interested in the information; 3) many existing DTN routing protocols [8] require complex offline processing to achieve optimal performance, which is prohibitive in HUNETs because they consume excessive resources and the needed data are usually impossible to get. B-SUB overcomes these problems by employing content-based publish/subscribe to facilitate infrastructure-less communication in HUNETs, and relies on **users' interests to guide content routing.**

Fig. 2 depicts the concept of a publish/subscribe system. Fig. 2a shows the architecture of the traditional publish/ subscribe (pub/sub) systems, where a central broker connects message producers (publishers) with consumers (subscribers). Fig. 2b depicts the pub/sub system in HUNETs. A swarm of nodes form a mobile broker network. Multiple nodes serve as brokers to carry messages for users. They are distributed and are constantly changing connec-tions due to mobility. These properties make it difficult to implement an efficient pub/sub system in HUNETs. We can still logically treat a swarm of brokers as a central broker, but this abstraction does not provide insights about the structure of HUNETs, nor does it improve the efficiency of information sharing. We take a radically different approach in designing B-SUB to address the unique requirements of HUNETs. B-SUB exploits the peer-to-peer communication pattern in HUNETs, and lets all users exchange their interests during random contacts. Messages are then forwarded to interested users by following the trails of interest propagation. More details are presented in Section 4.



(a) Traditional networks (b) HUNETs/DTNs

Fig. 2. High-level illustrations of the pub/sub system in traditional networks and HUNETs/DTNs. In traditional networks, A central broker con**nects publishers with subscribers. However, the "central broker"** abstraction is no longer valid in HUNETs, or is too expensive to maintain.

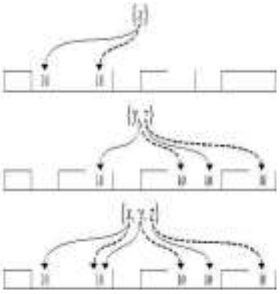


Fig. 4. Illustration of the M-merge of the TCBF. The fourth counter is the maximum of the two original TCBFs.

3 TEMPORAL COUNTING BLOOM FILTER

For a preliminary of the Bloom filter and analysis on its properties, please refer to Section 1 of the supplemental file which can be found on the Computer Society Digital Library at http://doi.ieeecomputersociety.org/10.1109/TPDS.2013.54.

3.1 Design of the Temporal Counting Bloom Filter

The TCBF is an extension of the counting Bloom filter. Similar to a counting Bloom filter, a TCBF also uses a vector of counters. Insertion of the TCBF increments the associated counters of the inserted key by a fixed value II, called the initial counter value

(ICV), instead of 1 in the counting Bloom filter. Each time a key **is inserted into a TCBF, the counters associated with the key'**s hashed bits will be set to the ICV. If the counter has already been set by some other keys, we do not change its value. In other words, the results of insertions are always a TCBF with multiple counters of the same value of II.

There are two ways of merging multiple TCBFs: the additive merging or A-merge and the maximum merging or M-merge. In the A-merge, as shown in Fig. 3, the counters are set to the

sum of the counters of the original filters. In the M-merge, as shown in Fig. 4, the values of the new **filter's counters are set as**

the maximum value of the counters of the original filters. The intentions of these two merging operations will be clear after we present the design of B-SUB