# The Quest for a Killer App for Opportunistic and Delay Tolerant Networks (Invited Paper)

Anders Lindgren
Swedish Institute of Computer Science
Box 1263
SE-164 29 Kista, Sweden
[andersl@sics.se]

Pan Hui
Deutsche Telekom Laboratories/TU-Berlin
Ernst-Reuter-Platz 7
10587 Berlin, Germany
[pan.hui@telekom.de]

## ABSTRACT

Delay Tolerant Networking (DTN) has attracted a lot of attention from the research community in recent years. Much work have been done regarding network architectures and algorithms for routing and forwarding in such networks. At the same time as many show enthusiasm for this exciting new research area there are also many sceptics, who question the usefulness of research in this area. In the past, we have seen other research areas become over-hyped and later die out as there was no killer app for them that made them useful in real scenarios. Real deployments of DTN systems have so far mostly been limited to a few niche scenarios, where they have been done as proof-of-concept field tests in research projects. In this paper, we embark upon a quest to find out what characterizes a potential killer applications for DTNs. Are there applications and situations where DTNs provide services that could not be achieved otherwise, or have potential to do it in a better way than other techniques? Further, we highlight some of the main challenges that needs to be solved to realize these applications and make DTNs a part of the mainstream network landscape.

## Categories and Subject Descriptors

C.2.1 Network Architecture and Design [

## General Terms

]: Design

## Keywords

DTN, opportunistic networking

## 1. INTRODUCTION

After Fall *et al.* proposed the Delay Tolerant Network (DTN) architecture [8] in Sigcomm 2003, opportunistic communication networks have attracted a lot of attention from the wireless and mobile network research community. The DTN architecture proposes a new communication paradigm where communication is possible even if end-to-end connectivity is never achievable. In just a few years, the research area has gone from a small topic considered fairly obscure by most researchers, to a topic that is very hyped. We see more and more people doing research in the area, and new workshops, conferences, and journals dedicated to the field start appearing. A large amount of work has been done on developing routing protocols and network architectures for different types of delay tolerant and opportunistic networks [23, 19, 22, 2, 12] (while opportunistic networks are a subset of DTNs, we will use the two terms interchangeably throughout the rest of this paper), and on understanding the properties of human mobility and the network environments that is created by that mobility [4].

The application scenarios of DTNs have mostly focused on niche applications such as alleviating the connectivity problems in rural and developing regions, interplanetary and military communication, and other adversary environments where end-to-end connectivity is not feasible. In this paper, we embark on a quest to find what would make a killer application for Delay Tolerant Networking, and which challenges must be overcome on the way there.

## 2. MOTIVATION

While the DTN research area has received much enthusiasm, there has also been fierce criticism. The skeptics question the utility and benefits of these types of networks, especially in the face of the more and more ubiquitous presence of networking infrastructure in the Western world. For a seemingly small fee, cellular network coverage is available in most locations, often providing data services as well as voice communication. Critics claim that such services can give the user an experience that is equivalent to the one expected from the Internet, and thus nobody would be interested in services from a DTN with the relatively longer delays that are inherent in such networks.

As opportunistic networking researchers, these skeptics are good motivators for us to reconsider our research and to push our innovations further. We need to think about whether or not we believe that DTNs can become a mainstream type of system that has an impact on the world. One way to do this is by considering what the potential killer applications for DTNs are. We can see from history that it may take a long time before the success of a system can be seen,


*CHANTS'09,* September 25, 2009, Beijing, China.

and that sometimes applications that the designers of the system did not see as useful, end of being immensely popular. Even though the early Internet provided great utility to its initial user base of scientists and military personnel, a *killer app* (the World Wide Web), was the necessary thing in order to bring it to the masses and make it what it is today. For the Internet, it took 11 years from the deployment of TCP/IP in 1981 to the very first WWW browser/server in 1992. As another example, the short message service (SMS) of cellular networks, which was originally designed to have a simple way of debugging the system, have taken off to become extremely popular, especially among the younger generation. How long will it take before we discover the killer app of DTNs, and are there applications around us that we do not understand the potential of?

Last decade, the research area of mobile ad hoc networks (MANETs), began receiving a massive amount of amount, and thus became a very hyped and "hot" area, which similarly to what we today see in DTN research, spawned many new publication venues and resulted in lots of people working on routing and related problems. DTNs and MANETs are closely related, and certain types of DTNs can be seen as a special case of MANETs, without the expectation that it will necessarily be possible to find an end-to-end multi-hop path through the network. The problem with MANETs was that a massive hype was created around the research area, which led many researchers to work on it, but to a large extent, people did not question the utility of the research they were doing. While there are some special purpose military networks that use MANET techniques, there are very few (if any) cases where MANETs have resulted in real, viable, mobile networks that are currently in use[1]. The problem was that the MANET community never found the *killer app* for the technology, and thus MANETs, while being a promising technology and interesting research problem, have not had much impact in the world even now, 15 years after it started becoming popular.

We believe that the current DTN research is more likely than MANETs to succeed as there are some fundamental differences. First of all, we believe that the fundamental paradigm shift in the way end-to-end communication is viewed is essential. As long as the connection oriented paradigm of TCP is kept, large multi-hop wireless networks will be very hard to realize due to the difficulty of establishing stable end-to-end paths. DTNs are taking the right approach to this type of communication, and can be a stepping stone to a working system even for the fully connected case. Secondly, the APIs that are being developed within the DTN community can be useful in more traditional Internet settings as well to help deal with unexpected interruptions. Finally, it is important to note that DTNs are attracting a lot more grassroots action than MANET ever did – MANET had its main use in a defense world, while DTNs are seeing lots of use in the developing world.

Thus, we are optimistic for the future of DTNs, but as a research community, we still need to ask ourselves what the potential killer applications for DTNs are. If we do not focus our efforts on this, we fear that the DTN research community might head in the same direction that the MANET community did several years ago. What do we want our lasting impact to be? In this paper, we challenge the mobile computing community to try to discover and identify the killer applications for DTNs. Is it possible to come up something which can give a new direction of DTN research? This is a long and arduous quest, and we do not claim to have found *the* killer app, but we will propose some potential applications that we believe may have an impact. More importantly, we also outline the challenges that the community needs to resolve in order to make this type of omnipresent DTN system a reality, as well as issues that individual researchers should keep in mind as they join us on this quest.

[1]Static wireless mesh networks are used in many places to provide Internet connectivity to a residential area or campus, but that is a special case of ad hoc networks, while most research dealt with multi-hop mobile MANETs.

# 3. NETWORK SCENARIO CHARACTERIZATION

We believe that DTN systems will progress to become the mainstream default networking paradigm, but we see two types of scenarios where they will be extra beneficial, and where we expect them to have their initial breakthroughs. These are outlined below.

## 3.1 Rural and Developing Regions

Over the past decade, communication infrastructure and services have become more and more pervasive in developed countries and urban areas. This has led to many changes in the way people interact, and the opportunities that they can get. Many services, such as banking and community information retrieval are now often expected to be done through the Internet. One major advantage of this technology is that in theory it enables people to access these services regardless of their location. This is however only partly true. If you live in a poor area in a developing country, or even in a remote area of one of the leading ICT nations in the world [18], chances are that you will not have access to this plethora of network services, and risk feeling like a second-class citizen. Recent statistics, illustrated in Figure 1, show a large skew in the distribution of Internet penetration towards the Western world and certain parts of Asia. Thus, the *digital divide* between people in different parts of the world, and between different groups within communities still exists. Delay tolerant and opportunistic networking can be used to enable people in remote and rural areas to instead use the network to improve fairness and equality between groups in society.

The network environments in such rural and developing regions span a large spectrum. In certain settings, such as remote mountainous areas [18], there is almost no infrastructure at all, and opportunistic communication is the only way to transfer data to and from the outside world. In areas like this, all legacy communication need to rely on an opportunistic approach. Extending the operators' networks into these regions is often economically infeasible due to the low population density or low disposable income in the population.

In other developing regions, there is some partial coverage of cellular networks, and there might be limited Internet connectivity available. However, the data service tend to be poor and unreliable. It is also often prohibitively expensive for the local population who need to prioritize the use of their money for other things. Short messaging can be performed using mobile phones, although a zero cost service for this would be welcomed. Applications for these areas are usually simple but enable a certain level of social in-

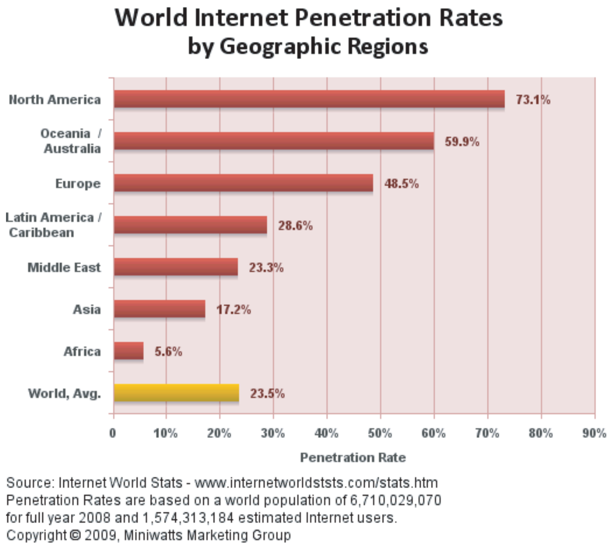


**Figure 1: Statistics of Internet Penetration Rates.**

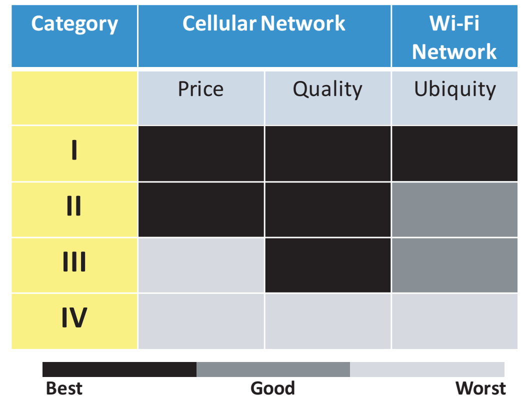


**Figure 2: Characteristics of Urban Environments.**

teraction or location services using short range radio. In emerging markets such as these, there are great potential for operators wanting to offer new services and are willing to explore new ways of providing them at a lower cost to such untapped markets. The mobile phone penetration rate is growing rapidly in such areas (as can be see from a report stating that in India, approximately 5 million new subscribers join the mobile phone market every month, as compared to a total PC penetration of 5 million in a whole year [13], and around 77 per cent of South Africans have a cellular handset [20] (this in a country where only 11% earn enough money to be registered for income tax)), so applications should reasonably be defined such that they can easily be used from a small mobile terminal instead of requiring larger computer systems.

## 3.2 Urban Areas

For urban areas, we group the network environment into four categories according to the *price* and *quality* of the cellular network (data traffic), and the *ubiquity* of free WiFi coverage. Figure 2 gives a summary of these categories.

**Category I**: Well-connected metropolitan area. Good quality 3G coverage with flat rate plans for data traffic and free WiFi networks available with high frequency. This is the scenario that has the least to gain from opportunistic networking, as most legacy communication can be done over the existing infrastructure. It is however still feasible to see opportunistic networks used in such settings to provide new types of services.

**Category II**: Well-connected urban area with ubiquitous availability of 3G coverage with a low flat rate for data traffic, but no ubiquitous availability of free WiFi access. As bandwidth in cellular networks is still small compared to that of local wireless networks (and is expected to remain so for the foreseeable future), there are still benefits of opportunistic networking for the dissemination of larger data items. In addition, for users not in a monthly contract, and some roaming users will be able to gain even more from opportunistic networking.

**Category III**: Emerging urban area with good 3G coverage, but prohibitive costs for data traffic on such networks, and low to medium density of WiFi access points. In this case, urgent or necessary communication can sent through the 3G network anytime, and an free WiFi access point can sometimes be found if the user is willing to walk a few minutes. The users are however not likely to want to use the 3G network to download large amounts of data such as high quality video, due to the cost, and it is not always feasible to move to a WiFi-covered location. In such scenarios, a combination of the cellular network, the wired Internet connecting the WiFi access points, and opportunistic communication can be used for data dissemination to enhance the user experience.

**Category IV**: Smaller urban area with good GSM coverage, but sparse 3G coverage. Low to medium density of WiFi access points. In this case, the GSM or 3G networks are not ideal for data traffic. This is similar to the situation in some developing regions, but the reliability of the cellular networks, and Internet connectivity can be expected to be higher. Urgent and important communication (of small size) can go through the cellular network, but it is unlikely that people will develop the habit of using cellular network for data service in such scenario. The relatively low density of WiFi access also prevents common usage of such techniques for communication in most locations. In this case, opportunistic networking can significantly improve the delivery ratio and delay of both asynchronous messaging and data push (e.g., email or news) services [10], especially if there is in-network storage available at the access points to allow for predictive prefetching [1].

# 4. CHALLENGES

There are many challenges associated with the type of networking discussed here. Such challenges both affect the technical design of the system, and the actions of the potential user base of a system, and are thus vital for finding a killer app. Some challenges that the community must overcome in order to survive are described below.

## 4.1 Technology Constraints

The current level of technology poses some constraints on what is presently possible to do. Examples of such constraints include limited battery capacity of mobile nodes, the connection-oriented nature of Bluetooth radio, power hungry WiFi radios, and diversity of mobile devices.

Compared to the increase in computational power and storage capacity, the advance in battery technology is very slow. Battery capacity is still small, and a battery of a laptop can usually last for 2 to 4 hours. This prevents mobile devices from frequent radio activities, and make delivering messages for others an altruistic behavior, as will be discussed more in Section 4.3.

DTN applications usually rely on short range radios for data delivery. The characteristics of such radios also form constraints on the design space. Bluetooth radio has low power-consumption (2.5 mW), but its connection-oriented property limits the number of pairing devices, and discovery and setup times are long, making short communication opportunities inefficient to use. WiFi has high data rates (up to 54 Mbps) and can perform broadcasting and handle fast synchronization of data, but its power consumption can be as high as 100mW, which will exhaust batteries quickly.

Currently, there is a large mobile platform fragmentation in the market. Vendors produce a plethora of handsets with different operating systems and capabilities, meaning that applications will have to be designed and implemented for each platform separately, making deployment and market penetration more difficult. It is vital that a common API is defined and implemented for each platform to make it easier for developers to create applications that can run on multiple platforms.

Users have grown used to expecting either instant access or no access at all to network services, and current user interfaces are not designed to cope with any other mode of operation (usually only providing an error message in case of network disruptions). Thus, one vital challenge to address in order to gain user acceptance for a delay tolerant system is to have a intuitive user interface. This should be able to cope with delays and disruptions in a way that is informative to the user. When possible to estimate, the user should be provided with information about the status of the network, such as estimated delivery time.

## 4.2 Understanding Human Dynamics

In order to design useful applications, it is vital to have a good understanding of the target environment and its users. Different types of user behaviour will result in dramatically different network conditions and will have a huge impact on whether or not a particular application will be of interest to the user base.

A fair amount of work has been done on studying human mobility traces in order to gain understanding of real life mobility patterns and how those affect the properties of the opportunistic networks that are possible in that environment [4, 9]. This work has given some insight into some fundamental properties of opportunistic networks, but much more is needed. We see the following challenges in this area:

**Lack of large scale human mobility data.** So far, most analysis have been based on a fairly small dataset, collected in a constrained setting, which is not representative for realistic use cases of the networks being studied. If one is interested in the properties of a large scale urban environment or conditions in a remote rural setting, it is probably not meaningful to study traces collected from 20 computer scientists at a conference or university campus. Thus, new ways of acquiring data that allows for a more realistic user base estimation and at a larger scale is needed. This might include novel ways of acquiring data, like in some recent work where ticket information from a public transportation system was used to gather a massive data set [15].

**Focus on other issues than mobility.** Most measurement and analysis studies to this date have been based on mobility and connectivity issues. These are important properties of the network, but equally important (but unfortunately harder to measure as it requires a network to be in place) is to understand traffic and usage models for the networks. This in turn depends on which applications are in place in the network and how the users use them. Usage patterns will also depend on the user context (habits, culture, country of residence, age, etc), so the same patterns will not apply to all users. The community need to make an effort to try to understand how the network will be used, even though it is very difficult as no such network (at a large scale) is present. Approximations of some use cases might be possible to derive from the way cellular networks are used, but that will most likely not be applicable to all types of applications.

## 4.3 End-user Based Networks – Participation Incentives

The most important consideration to keep in mind when designing a new network system is that there need to be some added benefit to the end user by using this network. Some of the major challenges to make these types of applications feasible relates to creating incentives for them to participate in the network in order to make the network sustainable.

**Tit-for-tat.** In current research projects, nodes are assumed to be part of the same project, and thus willing to help and participate in the network operation. In a large-scale real world deployment of the same type of system, it must be expected that many users will be selfish and try to exploit the system to gain performance, without giving up their own resources to help others. There are two main ways to combat this. One is to include some sort of incentive-based mechanism in the network, such that your utility of the network is greater if you are participating. The other is to try to ensure that resources are selected in a way such that their use does not inconvenience the owner of that resource.

**Battery power.** While on the move, battery power is one of the most valuable resources available in a mobile device. Thus, it is important to design the system such that the users can feel confident that their participation in the opportunistic network will not drain batteries so that their devices will become unusable. Much work on energy efficient protocols and duty cycling has been done in the past, but in addition to more work on such specifics, energy conservation should be a key consideration throughout the entire design process. It is also important to acknowledge the fact that different users have different energy profiles, and thus needs to be treated differently (users who charge their device every day can be more generous than users who only charge every few days).

**User penetration.** Many systems and applications require a certain amount of penetration of the user base to reach the critical mass where the true benefits of using the opportunistic system can be seen. When designing a system, it is important to consider how this can be reached.

Preferably, the system can be designed such that incremental benefits can be seen even through a small user base (if benefits are mainly local to a social group using the system, it may help as users will try to convince their friends to use the system in order to boost their own performance), but other incentive mechanisms to help overcome the bootstrapping problem also need to be considered.

**User involvement in design process.** The DTN research community can spend endless hours trying to come up with new brilliant applications and ways to use our networks. On the other hand, history has shown that the things that turn out to be the real killer apps for a particular service often is not what was envisioned by the original designers of the system. An obvious example of this is the SMS text messaging service of the GSM network, where nobody expected the immense use of this service among the young population that we now see. Thus, it is essential for the DTN community to involve potential end users in the design process wherever possible to ensure that we can detect potential killer apps as early as possible.

**Sustainability** Previously, many of the deployments that have been done have been under the auspices of different research projects. It is however vital that deployments are made with sustainability in mind, such that the users themselves can maintain the system and keep it up and running, even without the support of a research project. This is closely related to the previous issue about involving the users in the design process. If the users feel an "ownership" of the network, they are more likely to be willing to maintain it.

### 4.4 Operator Networks and Business Models

One way to get around some of the user participation issues is to implement the services as add-ons to the services already offered by current service providers. In this way, devices can come pre-installed with software that is not optional for the users to run, and thus a critical mass can be reached quicker. It is however important to ensure that sufficient concern is still taken to prevent unfair service degradation for some users, as that might cause them to move to a competing service provider. To avoid this, is it advisable that operators offer some form of credits to users for their forwarding efforts.

This method of deployment will obviously only be feasible if there is a business model where it makes sense for the service provider to support this type of application. Reasons for this could include:

- A new service that was not available before can be offered (including offering existing services, but at a lower cost or in areas where they were previously not profitable – this is particularly interesting for enabling operators to enter new emerging markets such as those described in Section 3.1).
- Performance of an existing service can be improved without increased infrastructure costs (as in Section 5.4).
- Low operating expense and robust service for the operators.

### 4.5 Security

Security is an important and challenging part of any networking system. In DTNs, this challenge becomes even greater. Much of the communication will take place through opportunistic forwarding by peer nodes, which cannot necessarily be trusted. It must be assumed that other users will try to read and modify messages being sent, so appropriate cryptographic measures should be taken on an end-to-end basis. This is however also challenging due to the possibly disconnected nature of the network, as it cannot be assumed that there will be a central trusted authority that can always be contacted for distribution of keys and certification purposes. Encryption of the whole message may however create problems for data-centric or content-centric forwarding [1, 12]. There must be a balance between data integrity and forwarding efficiency, which is yet to be studied.

Further, routing protocols need to take care to ensure that it is difficult for an attacker to create "black holes" in the network where all the data is being sent, but never forwarded out of. Accountability of forwarding nodes is important. Exposing of forwarding information (e.g. Name, Bluetooth ID, email addresses) in order to achieve efficient forwarding via different communication channels also create privacy issues (which would be crucial in applications such as the one proposed in Section 5.3). Application designers need to consider the trade off of these two issues, and social-based policies may be considered to strengthen privacy measures. It has been shown that due to the multiple path nature of DTN, the network itself, even without authentication, is robust in the presence of attacks (in a recent study, an attacker that has compromised 30% of all nodes only reduced delivery rates from 70% to 55% [3]).

## 5. POTENTIAL KILLER APPS

In this section we outline a few different applications that we believe could have a real impact on the DTN network community. We do not claim to have found *the* killer apps for DTNs, but these have interesting potential and we encourage the community to both consider investigating these further, but also add their own applications to the list of potential killer apps. For each of the applications below, we also indicate in which of the network scenarios in the Section 3 they would be beneficial, and which of the challenges in Section 4 that need to be addressed to make the application possible.

### 5.1 Telemedicine for Developing Regions

One service that is likely to be a killer app for DTNs in developing regions is the deployment of telemedicine systems. These are areas that are often plagued by diseases that are preventable or curable, if treated properly, but frequently end up killing the person suffering from it. There are several barriers to introducing ICT solutions in this domain including cost, unreliable infrastructure and lack of computer skills among staff [7]. While some telephone systems may exist, nothing that is advanced enough to transmit pictures and other information that can help a doctor diagnose a patient is available. Participatory design sessions with health staff, and pilot studies at clinics in South Africa, suggest that one way to deal with the challenges above is to implement telemedicine using store-and-forward Voice-over-IP (VoIP) [5]. VoIP is accessible from devices that are similar to traditional telephones, and thus can be used by those that lack computer skills. VoIP services can also be developed relatively cheaply because of the availability of open source software, and can be deployed without fixed infrastructure or support from a network operator [16]. The store-and-forward nature of such a service makes it ideal for deployment over a DTN. Even though a purely voice-based system is fairly simple and will only help with minor diagnostics, once a system like that is in place, it is easy to deploy new services that include images and other media to improve the possibility for doctors to give the correct diagnose and prescribe treatment.

***Useful in:*** Rural scenarios.

***Challenges to address:*** Challenges from Sections 4.1, 4.2, 4.3, 4.4, and 4.5.

## 5.2 Social Network Services for the Developing World

The lack of Internet connectivity in certain regions in no way imply that there is also no need for Social Network Services (SNS) – we argue the opposite. Traditionally over the past several thousands of years, when no ICT was available, people have been using local face-to-face communication with their peers to explore their social networks in order to find and exchange information and goods. Because of technology constraints, people in these regions still rely on traditional social networks to distribute information. We think DTN-enabled social network services would be very beneficial to them [14].

The Short Message Service (SMS) available in cellular networks is a communication channel that has seen a rapid growth lately, with 25 billions SMS being sent in India in 2006. This should be compared to 12 billions in 2005, so it is clear that the growth is very rapid [13]. As this has proven to be a true killer app for the cellular networks, we envision that the SNS should try to mimic the simplicity and style of SMS messaging, but offering richer services at a lower cost and even where there is no cellular coverage.

Given the evidence above, and the constraint on network conditions, we see this type of SNS networking as a potential killer app for opportunistic communication. In addition to typical SNS services such as friend searching and management, the system should offer support for resource sharing, information seeking, and information dissemination. For example, a farmer can send a message via his Bluetooth phone to his friends nearby to advertise the availability of his tomatoes to sell, and the friends can help to propagate the message through the social network.

***Useful in:*** Rural scenarios. Urban scenario IV.

***Challenges to address:*** Challenges from Sections 4.1 and 4.3.

## 5.3 Communication in the Presence of Oppressive Governments

Traditionally, the Internet has provided a relative freedom to people to communicate with anyone about any topic. As Internet and related services have become more prevalent in the entire world, this new possibility for communication without control have made it immensely popular among people in locations where governments and other organizations try to control the population in a oppressive way. This was obviously not looked keenly upon by the governments in those countries, and there has been many occurrences of late where censorship, traffic monitoring, and other mechanisms have been put in place to prevent free communication.

Opportunistic communication can become a champion of free speech in such countries. By not using the infrastructure to transmit messages, but only relying on opportunistic forwarding between people, it will become much more difficult for government agencies to track the communication. This is similar to mobile versions of the Tor [6] and Crowd [21] anonymous networks on DTN, but using mobility and delay of transmission to further increase anonymity.

To make this a reality, much work on security in opportunistic networks must be done. It is important that it is difficult to determine both the original sender of a message and the identities of intermediate forwarders for their safety. It is also vital that a reliable and authenticated method is available to know when a message has been delivered to its destination to avoid rogue agents injecting fake acknowledgements to purge messages from the network.

***Useful in:*** Rural scenarios. Urban scenarios I-IV.

***Challenges to address:*** Challenges from Sections 4.2, 4.3, and 4.5.

## 5.4 File Sharing and Bulk Data Transfer

Even in situations where cellular data access is relatively cheap and reliable (such as categories II-III in Section 3.2), the bandwidth offered by such services tend to be orders of magnitude smaller than what is offered by home broadband networks and also local wireless communication technologies. Thus, it is not very appealing to use the cellular data network to transfer large files. It is often better to only use the cellular network to transmit the request for some content, and then use delay tolerant techniques to deliver the data to the mobile device. While this technique can improve performance for dissemination of all types of large data items, it is even more beneficial if the data access patterns are somehow localized such that users in a certain area are more likely to request a certain data item (could be a video of the local news, or the course work among a group of students). Such properties increase the probability that data can be found locally among other nodes, and as such improve performance.

In large cities, where people meet many other every day, for example in public transportation systems, it is likely that the network of opportunistic contacts will be dense enough to provide a good means of spreading information, especially information that is likely to be of interest to a large part of the population such as the latest newscast or a new episode of a popular TV series (which of course creates a whole new set of challenges regarding copyright and DRM issues that will have to be addressed as part of designing this system).

### *5.4.1 Operator Benefits*

In addition to purely opportunistic forwarding between mobile nodes, network operators can add storage to the network such that if it is possible to predict where nodes are moving, parts of the content can be prefetched to WiFi hotspots where the user will pass in the future for fast download [1]. This can also be combined with the opportunistic forwarding between nodes as it has been shown that utilizing a combination opportunistic forwarding and access points can greatly improve performance of such content dissemination in networks of sparse infrastructure [10].

There are several benefits for the operators to add such services to their networks. First of all, they gain a new service that they can offer to their customers for added value. In addition, this method of content distribution can also reduce the operating expenses for the operator. If users are already paying a flat rate for data access, there is no added benefit for the operator when users download more content, but instead it will only consume network resources. Utilizing opportunistic communication will enable them to offer the same service, but with less resource usage. Operators have already realized this issue on fixed network, and tried to use DTN-like approaches to do bulk data transfer on the Internet [17]. We believe this will sooner or later happen to the cellular network if a flat rate is imposed on the service.

***Useful in:*** Rural scenarios. Urban scenarios II-IV.

***Challenges to address:*** Challenges from Sections 4.2 and 4.3.

## 5.5 Share Air Minutes

Even with ubiquitous availability of 3G coverage with a low flat rate for data traffic and excess air minutes for voice traffic, many mobile phone users are still on a pay-as-you-go mode, where pre-paid credits are bought and used for calls. In addition, users located outside the coverage area of their own operator pay excessive roaming charges to use the network of another operator. It is possible to leverage opportunistic networking in such a scenario by allowing the contract users to share their excess air minutes to the prepaid card users, or from the local contract users to the roaming users.

Hui *et al.* propose using opportunistic networking to allow mobile phone users to share their unused contract minutes [11]. A prepaid card/roaming user can connect her phone to a sharer's phone and make her own phone act as a headset of the sharer. The shared phone acting as the server then diverts the voice traffic to the cellular network via the phone's cellular link. There is a well defined business model here: the contract user would benefit from selling their unused minutes, the pre-pay users would benefit from cheaper calls, and the operators can gain extra revenue on minutes *that have already been sold* if they could receive a percentage of the value of the resold minutes.

While this is technically possible today, in order to realize a system such as this one, a system must be developed where phones are able to estimate if there are excess minutes available or if the contract user will need them all himself. This could initially be manually configured, but should ideally be automated. A major challenge (which could also enable other applications) is how to deal with the micro-payments of air time in a secure manner. In order to be able to maintain calls of acceptable length, it is also important to be able to estimate which other person will remain in range for local wireless communication long enough to finish the phone call.

***Useful in:*** Urban scenarios I-IV. Rural scenarios with good cellular coverage.

***Challenges to address:*** Challenges from Sections 4.1, 4.3, 4.4, and 4.5.

# 6. CONCLUSIONS

In this paper, we challenge the mobile computing community to envision what potential killer applications for DTNs would be. We identify important characteristics of the targeted network environments, and challenges that must be addressed in order to make real-life DTN systems feasible. While we have outlined a few potentially beneficial applications in this paper, these are mainly given as inspiration to start others thinking about potential killer apps for DTNs. We hope this can trigger a discussion within the DTN research community regarding the future of the research area, and what the potential killer apps are. This is vital for the survival of the research area and to help it mature into real systems that are in daily use, providing real services to real users.

With the wide variety of backgrounds that members of the DTN community have, a multi-faceted application landscape should lie ahead of us to explore. Thus, we urge everyone in the community to use their creativity to overcome the challenges and come up with new ways to use the network to change the way people interact. The most important consideration to keep in mind when designing a new network system is that there need to be some added benefit to the end user by using this network. It is not meaningful to create and deploy applications just because they provide a neat research exercise, but we need to strive for real impact!

## Acknowledgements

This work has been partly performed within the SICS Center for Networked Systems funded by VINNOVA, SSF, KKS, ABB, Ericsson, Saab Systems, TeliaSonera and T2Data.

This work has been carried out in part within the IST 7th Frame- work Programme Integrated Project 4WARD, funded in part by the Commission of the European Union.

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