Wireless P2P: Problem or Opportunity?

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***Abstract*—P2P is currently considered a problem by many wired and wireless providers, especially because of the large amount of traffic it generates. However, given new technology developments such as Wi-Fi Direct, we see an opportunity for P2P in mobile settings that, rather than treating mobiles as second-class citizens, seeks to take advantage of their capabilities over stationary devices. In this paper, we outline a new approach for fully decentralized mobile P2P that allows mobiles to run a variety of services and at the same time alleviates data overload in mobile networks. We consider mobiles integral and a richer class of nodes, and assume that they are capable of forming P2P networks without necessarily relying on the aid of stationary hosts or servers. We present a new architecture based on JXTA middleware, which is meant to not only optimize mobile resources, but also aims to take full advantage of the features that mobiles offer, such as mobility, ubiquity, location-awareness and sensors.**

***Keywords*-Wireless; Peer-To-Peer; Mobiles; Broadbands.**

I. Introduction

Mobile broadband networks currently serve not only users of mobile devices but also subscribers that, for reasons such as lack of coverage of wired networks, convenience of mobility, or price, choose mobile broadband as their primary connection. Thus, the scenarios where P2P is currently used are wide-ranging, with mobile devices connected either to a mobile network or to a wi-fi access point, and with stationary hosts connected either to a wired network or to a mobile network. While wired networks may also have some problems with traffic overloads due to P2P, these problems are especially exacerbated in mobile networks.

The introduction of the Wi-Fi Direct protocol [1] represents an opportunity to support P2P in a way that can effectively relieve the overload on some mobile networks. Both Internet Service Providers (ISPs) and consumers could benefit from this. Wi-Fi Direct will allow a mobile to connect directly with another mobile in its range that is also running the protocol, with no hubs or routers are involved. Data rates are expected to be over 250 Mbps with a coverage range of about 100 meters [1].

In this paper, we present some of the main issues that motivate the need for an alternative strategy for mobile P2P. We then present a new middleware framework based on JXTA to support mobile P2P systems that, amongst other capabilities, takes advantage of technologies such as Wi-Fi Direct.

II. P2P, Mobile Networks, and Emerging Technologies

A. P2P and file demand

As reported by Gigacom in 2009, the ISPs of wired networks have long considered P2P as a "voracious, bandwidth-eating monster" and have adopted aggressive traffic shaping policies and bandwidth caps in order to stop P2P traffic from overrunning their networks [2] [3]. Operators of cellular networks are paying closer attention to P2P traffic, which has become a problem in mobile networks too [2]. Many mobile providers have adopted traffic shaping policies to throttle P2P traffic at least during certain parts of the day (e.g., [16] [4]) or even blocking it completely [5].

According to a study conducted by Allot Communications and published in 2010 [6], P2P is the single largest factor leading to congestion. In mobile broadbands it accounts for 34% of bandwidth utilization in the 5% of users generating the largest amount of overall traffic. However, the study also reveals a rapid growth in HTTP traffic during 2009. Allot reports that in the second half of 2009 "HTTP downloads grew by 73%, and have become a feasible alternative for massive file sharing" [6]. In fact, a number of HTTP services are becoming extremely popular to share files, for example one-click hosters (e.g., RapidShare, MediaFire, MegaUpload, etc.) and other file hosting services, such as DropBox and LiveMesh. These services typically offer free or paid plans for users to upload and download files via HTTP. RapidShare reports to be currently hosting over 10 petabytes of data.

These facts suggest that the traffic problems in many current networks are not solely caused by P2P technologies, but rather by the rapidly growing demand for file sharing and other services. Should P2P technologies disappear, the current problems will likely remain, but shifted towards other existing or yet to emerge technologies. Additionally, an increasing number of paid services currently offer virtual private networks that can be used to tunnel and encrypt any type of traffic, including P2P, which is thus disguised and can circumvent ISP restricting policies.

B. Mobile Broadbands

Mobile broadbands, which allow wireless access to various Internet services through 3G, GPRS or other cellular networks, are becoming very popular worldwide. According to the statistics collected by Allot Communications, mobile broadband usage has increased of 72% in the second half of 2009 [6]. Mobile broadbands are being more and more widely used as a replacement for wired connections to exchange data. Verizon reports a wireless data revenue rise of 41% from 2007 to 2008 [7].

It is predicted that the number of mobile devices may pass the number of PCs and laptops by 2013 [31], which directly translates in a further increase in the number of users of mobile networks. Currently the 3G network counts about 1 billion subscribers, which are expected to reach 2.8 billion by 2014 [31]. A few providers have been trying to relieve their cellular networks by spreading wi-fi hotspots in some areas with particularly high traffic so that customers can use them in place of the 3G network for data transfers. This approach is clearly expensive and requires adding hardware and infrastructure.

However, 3G is mainly designed for voice traffic, which is much less bandwidth intensive than data traffic. Although the network has a data overlay capability, the latter is designed for bursts of data rather than continuous streams. For this reason, a continuous stream of data, which is often seen in P2P transfers, represents a problem for a mobile network. If many users are transferring large amounts of data, this will clog the network and leave other subscribers unable to access their own services [8].

Additionally, 3G networks have intrinsic limitations in the number of connections that a sector can accept, regardless of the amount of data transferred. Thus, whenever many nearby users try to access the network simultaneously, as often happens during social or emergency events, some users may be denied a connection because that sector of the network has already reached the maximum number of connections. Little can be done to prevent this problem, and even setting up the cellular network to reset connections more often provides limited results. It is estimated that 40% of the connections transfer less than 100 bytes, however many mobile applications automatically attempt to establish very frequent connections [31] and this greatly contributes to quickly clogging the mobile network.

One of the possible problems with restricting P2P usage in mobile networks is that the experience of their subscribers may significantly degrade, as users are unable to reach acceptable speeds in P2P communications. The possible dissatisfaction in their service may have a negative impact on mobile broadband ISPs, as customers may feel like the broadband subscription is not worth paying for. In fact, subscribers are often expecting their mobile networks to perform in much the same way as fixed networks and to be able to do the same things they would do on a normal wired network [2]. On the other hand, as other non-P2P services that generate high amounts of data gain popularity, restricting P2P becomes less and less effective to relieve overload problems.

C. Emerging Technologies

The upcoming release of the Wi-Fi Direct protocol [9] holds promise for promoting the feasibility and convenience of fully distributed wireless technologies. The Wi-Fi Direct protocol uses physical P2P communication in that it allows wi-fi devices in range to talk to each other without the need of intermediate wireless access points or routers. While few devices already support the protocol [10], the Wi-Fi alliance has announced that the wi-fi cards of many existing wireless devices can be made compatible with Wi-Fi Direct through upcoming software upgrades [1].

Since Wi-Fi Direct does not require any special hardware or infrastructure and can be installed on virtually any device with a wireless card, it is not unreasonable to expect that the concentration of devices running the protocol will become high in populated areas. This implies that in general each device could easily find a number of other devices in its range, which provides an opportunity to build chains of local connections. Additionally, even if two devices are not in each other's range, a connection could be established using multiple hops through other intermediate devices.

While P2P systems in theory can always be built on top of centralized network technologies, and the advent of 4G [1] will make data transmission over mobile networks more efficient, relying on fully distributed technologies can be beneficial for several reasons. Certain areas, for instance, may always lack coverage. The cellular network may be overloaded, or too expensive for some users, or mobile providers may decide to block P2P. Also, in certain countries where heavy censorships are in use to limit the freedom of communication, fully decentralized technologies may be a viable alternative to exchange information circumventing censorships.

III. Driving Applications

A wide range of services will benefit from mobile P2P and could be run in a Wi-Fi Direct supported P2P system. The heterogeneity of mobile devices and the desirable compatibility of the P2P system with stationary hosts could create a pool of different features, with peers complementing each other. Consider the following possible areas of application:

- *Voice communication.* The success of voice-over-IP (Voip) P2P applications such as Skype shows that P2P networks are good enough to provide time-sensitive services

[1] 4G network technology for mobile networks is just now starting to be tested, with the two main competitors being WiMax and LTE [11]; it is not clear when it or the other technologies will actually be more generally deployed.

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such as real-time audio and video communications. Voice communication does not necessarily need a dedicated infrastructure, nor a lot of computational power or bandwidth, as shown by Skype measurements [17].

- *Text messaging.* Being a time-insensitive service, text messaging can easily be implemented using mobile P2P, through multiple hops if necessary. Each peer would buffer a message only until it can be forwarded to another peer closer to the destination. By using epidemic routing [34], a time insensitive message can travel long distances under the assumption that at least some of the peers move in space.

- *Dissemination of traffic information.* It is becoming more and more common for smartphones and other mobile devices to have GPS capabilities. This allows for dissemination of information about local traffic in a P2P fashion. For instance, the GPS function of a mobile could automatically compute the mobile's speed and infer the degree of traffic congestion. Such data could be transparently transmitted in a P2P fashion, to help other drivers choosing less congested routes [26].

- *Dissemination of emergency data.* During emergencies, many nearby people typically try to send or retrieve information through their phones and it may happen that the number of attempted connections exceeds the number of connections that a specific cellular network sector can accept. The information could be shared in real-time and received by anyone that has a mobile connected to the P2P network. The devices do not need to be connected to an access point, nor to have access to the cellular network. This works well also because many emergencies are local, and the data can be spread in a precise area.

- *Photo/video sharing during an event.* Events such as sports or meetings of any kind encourage people that share a common interest to gather together. Their proximity allows a local mobile P2P network to be formed, and thus peers can share photos or videos (or any other type of information relevant to the event). It is well known that such events represent a tough challenge for mobile networks because of the high number of connections within a small area. Video transfers, which can be especially bulky, currently represent a big portion of the mobile traffic and are quickly growing [12].

- *Last–mile connectivity.* For people living in areas that are not covered by cellular networks or by Internet connections, such as farms in rural areas, a self-supporting mobile P2P network can be an alternative, assuming there are enough nodes that act as bridges between the uncovered area and an area where an Internet connection is available.

- *Local service networks for hospitals and other organizations.* Some corporations, especially in poor countries, cannot afford expensive LANs due to the costs of setting up and managing an infrastructure. In addition, the personnel may be often in movement and their having access to standard wi-fi connections may be sporadic. A corporate, protected mobile P2P network can allow personnel to be securely connected to each other at any time and with relatively low costs.

- *Local social networking.* Social networks are becoming very popular, and the integration of location information, while still immature, will provide powerful capabilities. In addition to promoting these capabilities, the proximity of mobiles allows the dynamic creation of location-aware social networks.

- *Multi–player gaming.* Even without an Internet connection, a mobile peer could find players for a multi-player game in the local P2P network. This allows peers to play games requiring more than one player. that otherwise could not be played alone.

IV. Current state of P2P support for mobiles

Currently, P2P exists in mobile networks in three different forms.

- *P2P protocols designed for stationary hosts but used in mobile broadbands.* Many subscribers use their mobile broadbands through USB cards connected to laptops and PCs. These users often run P2P applications designed for wired networks, often expecting comparable performance with the same application running on a computer connected to a wired network [2]. This can be highly inefficient because traditional P2P protocols are not optimized for mobile networks, which clearly have different parameters and capabilities. Additionally, this approach does not take advantage in any way of the added features and capabilities that mobile devices can have compared to stationary hosts, such as mobility, ubiquity, and sensing.

- *P2P protocols where mobile devices are considered weaker nodes and thus have to rely on stationary hosts.* In several P2P systems (e.g., [18] and projects based on JXME, JXTA in Java Micro Edition), it is assumed that mobiles need stationary hosts that relieve them from the computational load derived from being part of the P2P network. Mobiles typically have their queries to and from other peers mediated by a stationary node, which acts like a proxy. While in the past mobiles had indeed very reduced computational and storage capabilities, this is changing. At present, many mobile devices have better computational capabilities than PCs had ten years ago and are suitable for properly designed P2P technologies. Additionally, the proxy approach greatly reduces the applicability of mobile P2P systems, which cannot take advantage of the proximity of other mobile devices unless they can connect to a stationary host running the P2P protocol.

- *Ad-hoc and application-specific P2P systems.* A large number of different P2P systems for ad-hoc networks have been proposed, either relying on existing protocols, such as Bittorrent ([33], [13]) or adopting new ones (e.g. [26], [30]). The fragmentation in P2P protocols for ad-hoc networks, along with the incompatibility of the different protocols,

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does not maximize the opportunities for cooperation of the devices. In fact, a device cannot easily find other nodes running the same P2P protocol and, since mobile P2P heavily relies on the high number and proximity of peers for efficiency, this represents a significant disadvantage. Additionally, since there is no widely established middleware framework, each new P2P application needs to be developed from scratch.

A mobile P2P middleware framework may represent a significant improvement towards an efficient mobile P2P system. A middleware framework can support basic building blocks for protocols, and thus allow for the intercommunication of services and applications with different purposes built on the same compatible protocols. This implies that mobiles running different applications, but using the same protocol, could still cooperate on various tasks that are vital to the P2P network (e.g., query routing and peer/resource discovery). Additionally, new applications do not need to be developed from scratch, but instead can rely on the existing building blocks, and only the application-level development is necessary for a new service. Tailoring a P2P system on a mobile environment also means that it can be designed to take full advantage of the capabilities that mobiles have, such as mobility, ubiquity and sensing. At the same time, it can be optimized to take into account the different features that mobile networks exhibit.

V. Mobile-optimized mobility-optimized JXTA

Mobiles have several advantages over stationary hosts, mostly deriving from their capability for mobility. Since mobile devices are used in a variety of contexts, they can also carry information to and from each context. Additionally, mobiles can be tailored to the needs of their owner and of the surrounding environment. While a number of mobile P2P applications have been proposed, there are very few existing middleware frameworks, and they typically do not take the physical location into account.

JXTA, an open-source middleware system developed by Sun Microsystems in 2002 [14], is a good basis for versatile mobile P2P middleware that can be adapted to emerging technologies such as Wi-Fi Direct. The additions and extensions that we are developing take advantage of the added functionalities of mobiles, and at the same time, seek to improve the performance of JXTA-based networks in highly dynamic environments.

Traditionally, JXTA is organized in three basic layers. The core layer includes mandatory JXTA functionalities that are strictly necessary for the JXTA network to function properly. The service level includes fundamental higher-layer services, designed for flexibility and extensibility. The application layer includes a variety of applications that can be developed on top of the other two layers.

Figure 1 shows the structure of our mobile-optimized, mobility-optimized JXTA. The orange blocks represent parts of our system that differ from traditional JXTA. At the core layer, our focus is on JXTA's grouping abstraction. In JXTA, groups of peers provide a minimum set of given services and/or share specific interests. The group structure improves the performance and limits the load on each node by restricting the scope and the number of peers to query. We extend the peer group structure so that, in a true P2P communication scenario, that grouping criteria can be based on the physical location of nodes. This grouping extension promotes good performance by minimizing the number of hops that messages travel. Note that scoping is not restricted since a peer may be a member of both "local" and "remote" groups, and thus can also act as an intermediary for nearby nodes that only have a direct (as in Wi-Fi Direct) connection. Other core layer features, such as peers publishing XML-represented advertisements for resources (peers, groups, pipes and communications services), assigning IDs, and the various levels of support for authentication and privacy, remain the same as in the traditional JXTA.

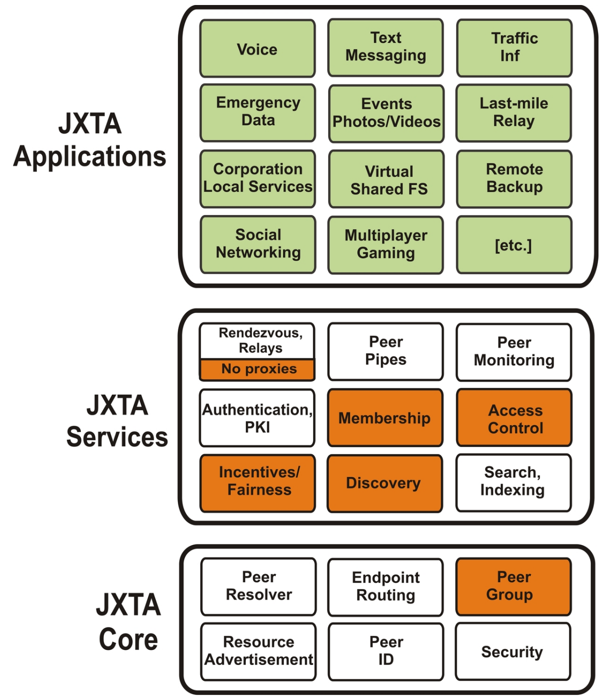

Figure 1. The three layers in our mobile-optimized JXTA. The colored blocks represent components that we either modify from the traditional JXTA (in the core and service layers) or introduce (in the application layer).

In JXTA, peers can run rendezvous and relay services. Rendezvous peers improve the efficiency of the network, as they maintain global advertisement indexes and play an important role in resource discovery. Relay peers are used to communicate with unreachable peers (i.e., those behind firewalls or NATs). The typical JXTA approach towards supporting minimal-edge peers (traditionally identified with mobile resource-limited devices) has been to establish proxy

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peers that mediate all the communication with the minimal-edge peers to allow them to access JXTA functionalities. Proxy peers are no longer absolutely necessary in our mobile-optimized system. In fact, current devices are powerful enough to be part of a P2P network without the need for stationary hosts to act as a proxies.

Consequently, at the service layer, we focus on the following extensions. In traditional JXTA, the membership service is used to securely establish identities and trust within a peer group, while the access service is used to validate requests of resources, made by one peer to another. In a highly dynamic environment where mobiles are continuously moving and thus causing changes to the structure of groups, it is virtually impossible to enforce strong rules for membership while maintaining efficiency and flexibility. Since having more peers in the network can lead to better performance, resilience and availability of services, it is convenient to have a loose policy for membership. Thus, we allow location/proximity to be a major criteria for access control in our system, as peers that happen to be geographically close represent an opportunity for efficient connections. Blacklists are used for peers that misbehave. Additionally, existing JXTA cryptographic tools can be customized to ensure an adequate level of privacy and authenticity, implemented at the peer level, rather than at the group level. Each peer is thus able to independently decide whether it wants secure connections, possibly only with trusted peers.

Traditional JXTA does not provide any specifications to ensure fairness or provide incentives. However, whether services are provided for free or for payment, incentives represent a fundamental component to encourage P2P resource sharing. Relying on the generosity of each node can lead to widespread free-riding behavior, especially in a mobile context, where nodes typically have to take their battery usage into account. Incentives can be economic rewards, or they may be established through a more general fairness policy in the exchange of services. For instance, a peer can be granted access to a service only if it also provides that same service, or in a more flexible scheme, it can be granted access to some given number of different services if it also provides a given number of similar ones. Due to the variety of services that JXTA can support, and given the dynamicity of P2P interactions, our approach is that each peer be rewarded for any service provided to the P2P community in general, and not to specific peers only. A similar concept has been used by Efstathiou et al. in the design of their P2P Wireless Network Confederation (P2PWNC) [27], and differs from the incentive strategy adopted by many popular P2P systems (e.g., Bittorrent and Edonkey). We take advantage of code mobility feature of JXTA [22], [25] which allows services to be added dynamically, not only by loading a pre-installed module but also by downloading from a remote source, such as another peer, the code needed to run a service. This provides further flexibility for a fairness scheme.

The discovery protocol is used in JXTA to find advertisements published by other peers within a group. To provide better availability of content, it is convenient that the discovery protocol also include the capability of retrieving content from peers outside the "local" group. Peers connected to the Internet through a wi-fi connection could, for example, retrieve content located far away and inject it in the local P2P network. A similar approach is described in [33].

We make use of JXTA support for a fully decentralized search infrastructure, which is based on resource indexing through distributed hash tables (DHT). Despite that this requires more computational resources than other search methods such as flooding, it is much more efficient as to network usage, which is particularly important in mobile broadbands.

VI. Related Work

Mobile P2P applications have typically not considered the geographical location as a prime concern. We are not aware of any P2P system that is specifically designed to optimize Wi-Fi Direct connections.

A number of potential mobile P2P applications have been proposed, for either new (e.g., [26], [30]) or existing (e.g. [33], [13]) protocols. As for middleware solutions, we refer to [28] and [32] for an extensive list. Many of the existing middleware frameworks present similarities, especially in the communication and resource discovery schemes, while the different scopes of each middleware determine some of the intrinsic differences among them, such as optimizations and sets of offered primitives. The great majority of the the middleware frameworks in [28] and [32] are currently discontinued.

Regarding JXTA-related mobile P2P, several works by Bisignano et al. present a JXTA-based middleware for MANETs (Mobile Ad hoc NETworks) [22], [19], [21], [23], [20]. In these works, a software layer is added on top of JXTA, with the main purpose of creating optimizations for advertisements and connections in MANETs. Results shown through simulations appear to be encouraging.

In [35], a set of improvements is presented to specifically optimize file sharing by using JXTA-Overlay. The latter is a project that builds an overlay on top of JXTA to offer a set of commonly needed functionalities and basic primitives [15]. In particular [35] proposes a distinction among different types of advertisements, to be handled differently, and, according to JXTA-Overlay specifications, the use of *broker* peers to govern the JXTA P2P network. ContextTorrent [29] is a semantic context management framework for distributed searches among local and remote context-aware applications. It is implemented in JXME, which has been ported to Android. Finally, JXBT [24] implements a JXME infrastructure using Bluetooth. It enhances basic Bluetooth and overcomes some of its limitations, such as the reduced number of interconnectable devices and limited transmission range.

VII. Conclusion

In this paper, we have highlighted how P2P is currently a widespread reality in both wired and wireless networks, and the reasons why a new form of P2P, one that exploits upcoming technologies for fully distributed connections, such as Wi-Fi Direct, can be beneficial for both consumers and service providers. We also presented some of the applications that become possible with new forms of P2P. We described the main building blocks of a new JXTA-based P2P middleware architecture, optimized not only for mobiles but also for mobility and location awareness. We are in the process of implementing the system in Android and we plan on testing it using Wi-Fi Direct as soon as it becomes available.

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