Internet Protocol over Unconventional Wireless Interfaces

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Abstract

The purpose of this paper is to explore options for enabling ad-hoc Internet access for mobile devices over unconventional wireless interfaces, mainly using short-range radio communication methods such as radio-frequency identification (RFID), near field communication (NFC) or Bluetooth. Short-range, point-to-point wireless communications may pose difficulties for traditional TCP/IP implementations and this paper aims to find out which kinds of challenges exist and what possible solutions could be devised. This is achieved largely by summarizing and comparing existing research.

KEYWORDS: ip, internet, nfc, rfid, bluetooth, unconventional, point-to-point, wireless

Figure 1: An Internet kiosk: The user places a mobile device on the kiosk and an Internet connection is established

1 Introduction

Providing Internet access in public spaces is an interesting challenge. 3G and WLAN connections, typically used by mobile devices, are not always the most viable solutions. When traveling abroad, data roaming over 3G may be fairly expensive. WLAN usage often costs money as well. Also, both 3G and WLAN excel at draining mobile devices' batteries [3].

To complement and counter 3G's and WLAN's shortcomings, short-range radio communication could be used to provide ad-hoc, point-to-point Internet connectivity for mobile devices. For instance, Internet kiosks could be deployed in airports to provide fast and cheap Internet access. For such purpose, a radio technology that is rarely utilized to provide Internet connectivity could be used. A sketch of such setup is depicted in figure 1.

If a suitable high enough bandwidth and energy-efficient technology could be found, battery drain could be kept at an acceptable level when compared to 3G or WLAN connections. This would be tempting for those travelers who rarely have the possibility recharge their mobile devices. To add further benefit, the kiosks could be ad-funded, making their usage free for the user.

There are several radio technologies that can be considered for this use and that are unconventional from the IP point of view. While it is not relevant to go into their detail in this paper, a brief description of possible options and their benefits and issues is in order.

Radio-frequency identification (RFID) and near field communication (NFC) based technologies are one option. They can be employed, for example, to provide mobile authentication or payment services. Energy-efficient and fast short-range radio technologies have been researched (see [6]) and they could, in some situations, be used to convey Internet traffic as well. Such technologies are further interesting because they could be complemented by a technology [5] that supplies operating power to the mobile device over another wireless connection, reducing its battery drain even more. There is existing research on using a mobile device as a reader and writer to a passive tag (see figure 2) but the relation could be reversed, making the mobile device an active tag that would be read, written to and to which energy would be supplied.

In addition to RFID based technologies, there are other alternatives, such as the much more commonplace Bluetooth, today found in many if not most personal mobile devices. Research on IP over Bluetooth has already been done over a decade ago (see e.g. [1]). There is at least one commonplace use for IP over Bluetooth: Tethering mobile phones' data transfer capabilities to laptops.

Both the underlying radio technology and the networking protocols must be chosen carefully. Challenges exist in both layers. The choice of radio technology has impact in, for example, power consumption and the range of the connection. Radio technology is, however, beyond the scope of this paper.

The forming of a connection is an issue affected by

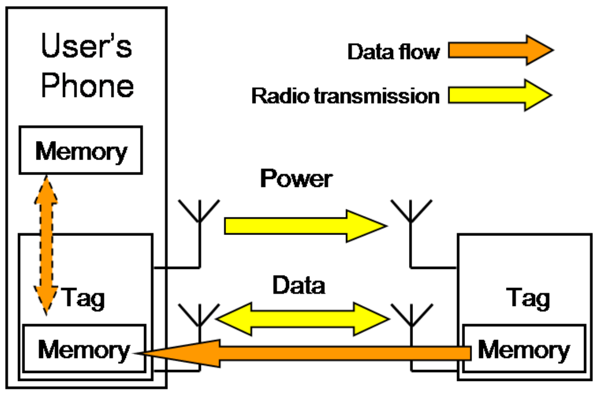

Figure 2: An architecture enabling a mobile phone to interact with a passive tag [7]

choices in both radio hardware and networking protocols. It is an important challenge as connection establishment must not take too long or be overly difficult for the user. Consider a businessman, for example, who wants to synchronize his email before hopping on the next plane at an airport. He does not have time to spend minutes or even tens of seconds configuring a new connection on his mobile phone – and even if he did, his attention span would probably not be long enough for him to be able to finish the task without getting frustrated, to say the least. In addition, ad-hoc connection establishment can be costly in terms of energy. WLAN, for example, consumes considerable amounts of energy before a connection to an access point is formed [3].

At the airport, there could be special Internet kiosks that would be stationary stands intended to be used by travelers passing by. Externally, the kiosks could be similar to automated teller machines (ATMs) using which one can withdraw cash from their bank account. The traveler could place a mobile phone near or on the kiosk and then be able to use the Internet. Like an ATM, the kiosk could have a screen that would show advertisements, thereby making Internet usage free for the traveler. Another, similar scenario would be that the kiosk would be intended only for a specific purpose, for example the synchronization of email, possibly for a certain operator only, and would operate quickly without any user attendance apart from the user placing the mobile device on the kiosk.

There are some challenges in this approach. Regular Bluetooth connections, for instance, are rather cumbersome to form [11]. From the viewpoint of IP, on the other hand, address configuration has an effect on connection establishment time.

From the network protocol perspective, some kind of compatibility with the TCP/IP stack must be implemented if Internet traffic is to be accommodated, be that either direct implementation or the possibility to bridge traffic to an IP network. Even if TCP/IP is directly used over the data link layer, dependent on the chosen radio link, there are issues and alternative approaches to be considered – for example, whether to use IPv4 or IPv6 or a stripped-down version of either one.

The paper is organized as follows. After the introduction, I look into the challenges involved in transferring TCP/IP traffic over ad-hoc point-to-point radio links, as well as some possible approaches to solve the problems. After this, I introduce some available or proposed solutions. Finally, I present my conclusions.

2 Challenges

Existing research on mobile ad-hoc networks (MANETs) often concentrates, as the name suggests, on networks. Also, they are often researched from the point of view of low-bandwidth devices such as wireless sensors. In the case of providing Internet connectivity for devices such as mobile phones or laptops over a short distance point-to-point connection, these are not such interesting points. MANET research on routing is not relevant for us due to the point-to-point nature of these connections. Likewise, saving individual bits by reducing header data is hardly an issue if the application itself might use tens or hundreds of kilobytes of bandwidth per second. However, this is not to say that MANET research has nothing to give to short range point-to-point ad-hoc connections, merely that the research stems from different needs. Naturally, for example the optimization of protocols for bandwidth efficiency does not hurt but it is not our main concern.

The interesting problems I have identified are the speed and ease of connection establishment and the ability to handle unstable connections.

The former is important because it is necessary for the user that the connection can be set up as quickly and as easily as possible [7]. The latter point, on the other hand, is important due to the short range of the connection.

A short range radio connection might extend only centimeters or tens of centimeters and it is important that the protocol stack does not get confused if the connection is interrupted for a while. It is to be noted, however, that the short range is not merely a nuisance. It would be ideal to be able to choose a service by proximity. In the email synchronization use case mentioned before, there could be separate kiosks for different operators or email services, and choosing the right one would be as simple as placing the mobile phone in the right place.

In the following subsections I present the problem areas in more detail.

2.1 Connection Establishment

2.1.1 Address Configuration

From the IP point of view, choosing a speedy address configuration method is the most that can be done to speed up connection establishment. As the connections in question are point-to-point, one might ask whether an autoconfiguration method is necessary at all – static addressing could also be used. For future extensibility, however, I find that autoconfiguration would be convenient, should there arise a need for multiple connections to a single spot such as an Internet kiosk.

In the IPv4 world, dynamic host configuration protocol (DHCP) [4] is the de facto standard for address autoconfiguration. Due to the nature of DHCP, it takes some time for the DHCP server to allocate a new address for a new host and for the new address to be taken into use by the host. It is faster to give an address to an already known host, i.e. a host that already has an allocated address. This, however, is hardly an advantage in the airport example mentioned above – the probability of an airline passenger reusing the same access point is presumably rather low. Some other method for address configuration would therefore be preferable.

IPv6 provides a stateless method for autoconfiguration [15]. It is a decentralized approach which, unlike DHCP, requires no central server. A router advertises its subnet prefix to a host which the host then combines with an identifier that it generates, often from the hardware address of the host's network interface. This method leaves no possibility for the network to manage the addresses in the network but this should be an acceptable caveat in our case. However, as IPv4 is still more widely supported than IPv6, an IPv4 compatible approach may be required.

2.1.2 Data Link Layer

While somewhat out of the scope of this paper, connection establishment related challenges on the data link layer of the TCP/IP model are also worth a mention. For instance Bluetooth connections, as mentioned earlier, are quite laborious to establish. The user has to first scan for nearby Bluetooth devices, then select the right one and initiate connection establishment negotiation between the devices. As the process requires user involvement, it is probably a much greater stumbling block to quick and easy connection setup than IP address autoconfiguration ever will be. Truly short-ranged approaches – tens of centimeters at most – have an advantage over regular Bluetooth, being able to select a service by proximity.

Another problem related with Bluetooth and its long range is that there may be many Bluetooth devices within range of each other and they may interfere with each other. Besides problems caused by radio interference, such as link level packet collisions, a problem called Bluetooth pollution has been identified. When a large amount of non-cooperating Bluetooth devices operate within an area, basic Bluetooth operations will cause negative interaction among the devices. For example, if a device wants to join a Bluetooth network, there may be an arbitrary amount of devices not in the network but within range. The devices may be in states that will cause hindrance to the connection establishment process by unnecessarily responding to the device establishing the connection. Bluetooth pollution can cause delays and may even prevent the connection from being established properly [2].

2.2 Unstable Connections

In the Internet, transmission control protocol (TCP) [10] is the most common way of providing a reliable, connection-oriented link between two hosts. One of the core protocols of the Internet, TCP was designed long before any wireless Internet connections became available.

TCP has mechanisms for avoiding and controlling congestion. The problem with congestion control is that when packets are lost, the protocol assumes they are missed because of congestion and starts altering its behavior according to that assumption. If they are, in reality, lost due to a temporary disconnection in a wireless link, the results may be undesirable, such as slowdowns in transmission rate. Another issue found in wireless networks is high bit error rate (BER), unlikely to occur in optical or copper wired networks, which causes some packets to be transferred erroneously at random, further confusing the unprepared TCP [16].

TCP Reno is a popular flavor of TCP [16]. After a connection has been started, TCP Reno will eventually enter a phase called congestion avoidance if the link is working properly. Packet loss – usually due to congestion in wired networks – is indicated by one of two symptoms. One is that the sender receives enough duplicate acknowledgements to a previously sent packet due to a packet sent later getting lost. The other is that it receives no acknowledgement at all, that is, the acknowledgement is lost, in which case the sender's retransmission timeout timer expires. In either case, TCP will eventually enter states called fast retransmit and fast recovery. This basically reduces the amount of data sent to half and then gradually increases it, causing a drop in transmission rate. When packet loss occurs frequently, due to frequent disconnections or a high BER, for instance, this may effectively cripple the speed of a wireless connection to a crawl.

Without going too much into the details of the different flavors of TCP, it can be noted that this can be a problem. Luckily, as wireless networking has become a reality, quite a bit of research on TCP over wireless links has been done (see e.g. [9]).

3 Solutions

As stated before, IP over high-bandwidth point-to-point ad-hoc connections using short range radio links is not the most common field of study. However, existing research on MANETs, for instance, is helpful as there are many common problems in ad-hoc networks and our ad-hoc connections. Besides standard TCP/IP solutions, many of the available solutions and propositions are, in fact, MANET related.

3.1 Connection Establishment

3.1.1 Address Configuration

In MANETs, handovers are common because the mobility of nodes. To enable seamless handovers, some method for autoconfiguration must be implemented. Hence, methods for that have been researched. There are stateless and stateful approaches as well as hybrids of both, such as PACMAN [17]. Similarly to IPv6 stateless autoconfiguration, PACMAN assigns addresses passively. That is, nodes assign addresses to themselves without consulting central servers which is very fast. However, one of the main concerns of PACMAN is the detection of duplicate addresses. In a truly point-to-point link, this should not be an issue as there are only two hosts in the network at any given time.

While it may be possible that duplicate addresses sometimes occur in some configurations – namely multiple point-to-point links to a host that provides the clients a common IP subnet for communication – standard measures taken by IPv6 stateless autoconfiguration, for example, should be adequate.

Addressing in Internet kiosks, for example, can be completely local, as there should be no need for centralized control of addressing. This would, in my opinion, call for a simple and lightweight autoconfiguration method. Furthermore, if the Internet kiosk would be intended only for a specific purpose, like operator specific email synchronization, it could be guaranteed that there is an IPv6 route to the email server. Hence, at least for such specific purposes, ordinary IPv6 with stateless autoconfiguration could very well be used.

Should plain IPv4 be chosen, some corners could be cut to make DHCP faster. In fact, Park et al [8] propose an improvement to standard IPv4 DHCP, designed especially for WLAN environments. Instead of the 4-way message exchange required when acquiring an address, their proposition employs a 2-message exchange. According to their performance evaluation, it offers improvements over the regular model. However, this model addresses problems peculiar to IP mobility where the actual DHCP server may be far from the WLAN access point. Nevertheless, it could possibly be used if DHCP performance is deemed unsatisfactory.

NanoIP [13] is a feature-rich solution intended for sensor networks and other environments where hardware resources and power supply are scarce and bandwidth is very limited. NanoIP's approach to addressing is to utilize hardware MAC addresses directly, with no intention to route anything outside the network except via a specific Internet gateway. If nanoIP was to be utilized in our scenario, global uniqueness of the MAC addresses should be guaranteed in order to avoid address collisions. NanoIP's strengths are perhaps more in the internal communication of a network consisting of a homogenous or at least controlled base of devices and in enabling access from an IP network to services on the nanoIP devices. Providing Internet access to mobile phones that can be owned and manufactured by anybody can be very different from collecting data from a wireless sensor network, the devices of which its owner has himself chosen and taken into use.

3.1.2 Data Link Layer

Solutions to the problems Bluetooth has with ad-hoc connection establishment have been proposed. These methods utilize some other technology to aid the process. There has been research on at least three assisting technologies: IrDA [18], visual tags [12] and RFID tags [11].

All of these methods are based on the user first making a visual sighting of the device that provides a service and then using a mobile device to interact with it without browsing through the menus of the device. The connection can then be established by using the data found in a tag (visual or RFID) or negotiating necessary details using another data transfer method (IrDA).

The tag-based options only require a passive tag on the device to which the user wishes to connect. The IrDA option, on the other hand, requires infrared communication capabilities from both ends. With IrDA becoming a rarity in modern mobile devices, this approach is quite obsolete. The tag based alternatives, however, are tempting, especially the visual tag based one, due to most modern mobile phones having a camera. User tests have shown that getting the Bluetooth device address from a visual tag is 24 times faster on average than using the standard Bluetooth Device Discovery model on a Nokia 3650/3660 camera phone [12]. Keeping in mind that the study was made many years ago and that camera phones' technology has advanced, it is likely that many if not most current camera phones can achieve similar results. Likewise, tests have shown that the RFID option, too, provides a significant increase in connection establishment speed [11]. However, RFID readers and writers are not found on many mobile phones.

3.2 Unstable Connections

ATCP [14] is an interesting approach to providing an efficient TCP connection over ad-hoc wireless networks. It attempts to fight problems caused by high BER, route recomputations and network partitions. The high BER problem and the network partitioning problem, caused by temporary disconnections in a network, are exactly the kinds of problems topical to wireless ad-hoc point-to-point connections. ATCP is a layer between the standard TCP and IP layers and it, being invisible to TCP, enables ATCP hosts to communicate with non-ATCP hosts as well. Instead of always assuming problems to be caused by congestion, it relies on explicit congestion notifications for congestion detection and distinguishing packet loss caused by congestion from error loss. It also uses separate ICMP Destination Unreachable messages for detecting changes in routing or network partitioning. Using these, ATCP can determine when to enter congestion control mode and when to just wait. However, it seems that there are no common, publicly available implementations of ATCP.

NanoIP also offers a simplified TCP implementation [13]. As nanoIP does no routing whatsoever, its authors consider congestion control to be unnecessary and hence left it out of nanoTCP. This is an idea that could be borrowed to our use as well and it might prove efficient as there should not be much chance for congestion especially at short distances. However, the use of the entire nanoIP stack may not be the best bet. While nanoIP might work fine with higher bandwidths and more powerful devices as well, its use in such cases is arguably unnecessary. It is, after all, designed for devices and networks limited in resources. Also, nanoIP requires special measures if interoperability with regular TCP/IP networks is needed.

IP over Bluetooth was researched already in the 1990s. The BLUEPAC IP approach proposed in [1] is concerned mainly with addressing and mobility. What is interesting from the TCP point of view is that BLUEPAC is intended to be used with regular TCP implementations with no modifications, suggesting that ordinary TCP might work well enough. In fact, ordinary TCP/IP usage over Bluetooth is quite common in at least one use case: Tethering mobile phones' 3G connections to laptops.

Judging by the research done on TCP/IP over mobile ad-hoc networks, it seems to be an interesting research problem. However, as the research has usually been done from the point of view of low-bandwidth devices and networks, proposed solutions take measures that are unnecessary from the high-bandwidth point-to-point connection point of view. It would likely be worthwhile to test the performance of TCP/IP and nanoIP over such links in reality – it could turn out that regular TCP/IP performs well enough. Should that be the case, it would be very convenient as a TCP/IP protocol stack is available on practically every host connected to the Internet.

4 Conclusion

The major concerns related to the topic of this paper are those of connection establishment and the handling of unstable connections. Connection establishment needs to be quick and easy even when making a connection between devices for the first time which usually is the case. Likewise, the connection must be able to handle transmission errors and short disconnections gracefully without crippling transfer rate.

Connection establishment related issues have been researched in the field of mobile ad-hoc networks. In our case, handovers, true IP mobility or control over address spaces are not important as a network connection is only needed as long as the mobile phone user needs to receive something from the Internet. Hence address autoconfiguration methods designed for MANETs may be too sophisticated for this purpose, making regular IPv6 stateless autoconfiguration seem far more tempting. DHCP, used in IPv4, could be used but it can cause delays. An optimized version of DHCP could also be implemented as plain DHCP offers unnecessary features for this purpose.

The choice of radio technology has a profound impact on the speed and ease of connection establishment. Browsing through the menus of a mobile phone in order to find a service and form a regular Bluetooth connection with it can take a long time. RFID or visual tags may be used to speed up the process dramatically.

Much of the research related to the subject of TCP and IP over short-range wireless connections concentrates largely on issues irrelevant to this paper, namely routing in networks and low resources on devices. The routing point is uninteresting because of the point-to-point nature of the connections in question. While mobile phones are hardly the best equipped devices in the world in terms of processing power and battery capacity, they are still vastly more capable than the simple sensor devices that many research papers concentrate on. It would be easy to get sidetracked and put effort into trying to save every possible bit of header data but that is not quite what is needed when the transfer rates can be way above tens of kilobytes per seconds.

Lacking actual test data, I would propose that, whatever the radio technology is, ordinary IPv4, or preferably IPv6, should be used for applications using high-bandwidth short-range point-to-point ad-hoc radio links. Instead of relying on a complete protocol suite designed for something else, such as sensor networks, the tried and tested TCP/IP stack may very well prove to be good enough for this use as well.

Further research could be done on the actual performance of TCP/IP version 4 and version 6 and, for example, nanoIP over Bluetooth and high-bandwidth RFID or NFC based links. Additionally, power consumption measurements of the tested configurations might prove interesting.

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