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Report
Wireless Data Throughput Testing on a Mobile Device Using WiFi and GPRS

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EXECUTIVE SUMMARY

This project report presents the results of a study on wireless communication data transfer rates for a mobile device running a custom-built construction defect reporting application. The study measured the time taken to transmit data about a construction defect, which included digital imagery and text, in order to assess the feasibility of transferring various types and sizes of data and the ICT-supported construction management applications that could be developed as a consequence. Data transfer rates over GPRS through the Telstra network and WiFi over a private network were compared. Based on the data size and data transfer time, the rate of transfer was calculated to determine the actual data transmission speeds at which the information was being sent using the wireless mobile communication protocols. The report finds that the transmission speeds vary considerably when using GPRS and can be significantly slower than what is advertised by mobile network providers. While WiFi is much faster than GPRS, the limited range of WiFi limits the protocol to residential-scale construction sites.

The study is based on a purpose-built, mobile ICT-supported construction management application – construction defect reporting. Traditionally site architects and engineers inspect a construction site for job phase approval and sign-off for progress of work. If a defect is detected, a report is made noting the location of the defect, the nature of the defect, and, where possible, an image of the defect. However, this information is generally recorded on paper, which contributes to the time consuming and disconnected workflow in defect reporting and management, leading to frequent errors and low efficiency. The purpose-built mobile computing application for the reporting and management of construction defect information includes functionality to take a digital image of the defect, locate the defect using GPS coordinates, annotate the defect with additional meta data, and then transfer the data over the wireless communication link to an off-site defect reporting and management database.

This mobile computing application for construction management demonstrates one application of mobile computing and wireless communication to address a specific problem in construction management. The widespread emergence of wireless networks and the rapid adoption of mobile devices have made these technological resources more practicable and cost-effective for a wide-range of nomadic computing applications. However, there exist risks in adopting the technology without an adequate understanding of their limitations. This study addresses the question as to the type and size of data that can be reasonably transferred from and to a mobile computing device given current network bandwidth availability and the type of applications that can be successfully deployed as a consequence.

Overview

Building defect reporting in the construction industry is a challenging and often time-consuming in terms of high rate of error and inefficiency. During the construction process, unpredictable circumstances lead to building defects; thus, the built structure is in a partial state of completion in which part of its "structure" exists only in the virtual world of CAD drawings. Current paper-based methods of building construction process documentation are becoming replaced by digital methods as technology advances and to improve the accountability and traceability of decision-making during construction. The paper-based approaches are often not organised and result in a bottleneck when trying to retrieve a specific piece of information. A shift to a digital approach in the exchange of the construction defect information can help speed up and streamline the process.

A typical scenario would involve a site foreman on a construction site reviewing one of the levels of the building. In surveying the level the site foreman may notice a number of construction defects and contacts the architectural and engineering offices involved in the project. A request is made that a representative of one of the offices is to conduct an on-site inspection to document, record, and send this information back to their respective office, located off-site, for evaluation and consultation. In turn, the office will make recommendations relating to the defect and concur on an appropriate course of remediation pertaining to that particular defect.

However, recording and sending data to and from the construction site to an off-site office is one of the more problematic areas in information technology for construction automation, and particularly for construction defect management. A mobile and wireless computing based application could assist in the remote telecollaboration between a construction site and off-site engineering office. This report describes one such application and the feasibility of the application by testing how much and what type of data can be reasonably captured, reported, and recorded.

1 Introduction

The availability in terms of coverage, reliability and speed of wireless communication has increased over the past decade. Significant developments have been made in the technology to provide reliable services. More recently there has been a trend to provide mobile data services in addition to voice. The current challenge for the mobile application developers is identifying the information needs and the appropriate wireless communication protocols which best meets end users' requirements for sending and receiving information. Many variables affect the speed and reliability of wireless data transmission and the concomitant mobile computing based application that can be reasonably supported.

The following reports on tests conducted at the Faculty of Architecture at the University of Sydney on data throughput transmission using GPRS and WiFi and a mobile device running a purpose-built construction defect reporting application written in Java. The aim of the tests was to develop an operational understanding of these two wireless data transmission protocols, especially to determine the *actual* speed and maximum size of data a user can reasonably expect to send over these wireless communication networks. Tests were conducted for each data transmission protocol and each test is conducted in the same environmental setting. Higher speeds are expected to become available as wireless networking is improved to carry live 'streaming' video, but these are still nascent in Australia. The choice of GPRS and WiFi is a practical one; both are widely available, generally accepted as reliable, and supported by a large number of commercially available mobile devices from PDAs to integrated mobile phones.

1.1 GPRS

The General Packet Radio Service (GPRS) is a non-voice value added service that allows data to be sent and received across a mobile telephone network. It supplements circuit switched data (CSD) and short messaging service (SMS). GPRS users specifically need:

- a mobile phone / PDA that supports GPRS
  → iMate PDA2k
- a subscription to a mobile network that supports GPRS
  → Telstra Network
- a destination to send or receive information through GPRS
  → server address: andy.arch.usyd.edu.au

GPRS facilitates instant connection whereby information can be sent or received immediately as the need arises, subject to radio coverage. No dial-up modem connection is necessary. This is why GPRS users are sometimes referred to be as being *always connected*. Immediacy is one of the advantages of GPRS (and SMS) when compared to CSD. High immediacy is a very important feature for time critical applications.

Theoretically, maximum speeds of up to 171.2 kilobits per second (kbps) are achievable with GPRS using all eight timeslots at the same time. This is about three times as fast as the data transmission speeds possible over fixed telecommunication networks and ten times as fast as current CSD services. However achieving the theoretical maximum GPRS data transmission speed of 171.2 kbps will require a single user taking over all eight timeslots without any error protection. Clearly it is unlikely that a network operator will allow all eight timeslots to be used by a single GPRS user.

The class of the device determines the speed at which GPRS can be used. The majority of GPRS terminals will be able to download data at speeds of up to 24 kbps. At the higher end, speeds are theoretically possible up to 171.2 kbps when 8 slots are assigned at the same time to a single user. Multislot classes are product dependant and determine the maximum achievable data rates in both the uplink and downlink directions. Written as

3+1 or 2+2, the first number indicates the amount of downlink timeslots (what the mobile is able to receive from the network). The second number indicates the amount of uplink timeslots (how many timeslots the mobile is able to transmit). The active slot determines the total number of slots the GPRS device can use simultaneously for both uplink and downlink communications. The iMate PDA2k is in GPRS multislot class 10 and is configurable between 4+1 and 3+2 which translates to having 4 downlink slots and 1 uplink slot or 3 downlink and 2 uplink slots respectively. The expected data rate for 4+1 is 8-12 kbps for sending and 32-48 kbps for receiving. However if using a 3+2 configuration then the rates differ, 16-24 kbps for sending and 24-36 kbps for receiving data.

In addition to the multislot classes, what category of class matters too as it indicates the mobile phone's capabilities. The iMate PDA2k used in this test falls into the category of Class B. Class B mobile phones can be attached to both GPRS and GSM services using one service at a time. Class B enables making or receiving a voice call or sending/receiving an SMS during a GPRS connection. During voice calls or SMS/, GPRS services are suspended and then resumed automatically after the call or SMS session has ended.

GPRS enables several new applications which have not previously been available over GSM networks due to the limitations in speed of CSD (9.6 kbps) and message length of SMS (160 characters) such as Web browsing and multimedia messaging (MMS). GPRS also enables a communication link to private networks via the Internet to enable data transfer between mobile device to server or desktop as is the case in the test procedure of this study. File transfer applications encompass any form of downloading sizeable data across the mobile network. Irrespective of source and type of file being transferred, this kind of application tends to be bandwidth intensive.

With GPRS, the data is split into separate but related packets before being transmitted and reassembled at the receiving end. Packet switching means that GPRS radio resources are used only when users are actually sending or receiving data. Rather than dedicating a radio channel to a mobile data user for a fixed period of time, the available radio resource can be concurrently shared between several users. This efficient use of scarce radio resources means that large number of GPRS users can potentially share the same bandwidth and be served from a single cell. The actual number of users supported depends on the application being used and how much data is being transferred. GPRS does impact a network's existing cell capacity. There are only limited radio resources that can be deployed for different uses – use for one purpose precludes simultaneous use for another. For example, voice and GPRS data cannot both use the same network resources simultaneously. The extent of the impact depends upon the number of timeslots, if any, that are reserved for exclusive use of GPRS. However GPRS dynamically manages channel allocation and allows a reduction in peak time signalling channel loading by sending short messages over GPRS channels instead.

The disadvantages of GPRS are that packets are sent in all different directions to reach a destination. This opens up the potential from one or some of those packets to be lost in corrupted during the data transmission over the radio link. The GPRS standards recognise this inherent feature of wireless packet technologies and incorporate data integrity and retransmission strategies. However, the result is that potential transit delays will occur. Cost of GPRS will also play a part in what is being transmitted and depending on the frequency of what is being sent too. These small costs can all add up and deter users from using this networking technology.

1.2 WIFI

WiFi refers to a set of wireless networking technologies more specifically referred to as 802.11a, 802.11b and 802.11g. It allows users that have a WiFi capable device, such as a laptop or PDA, to connect anywhere there is a WiFi access point available. The three standards referred to indicate the speed of the connection they are capable of supporting. 802.11b – which transmits at 11 Megabits per Second – is the most common, although it is quickly being replaced by the faster WiFi standards.

WiFi adds tremendous levels of convenience and increased productivity for users whose offices are equipped with WiFi. It can be said that WiFi and related consumer technologies hold the key to replacing cellular telephone networks such as GSM. Some obstacles to making this possible in the near future are missing roaming and authentication features, the narrowness of the available spectrum, and the limited frequency range WiFi offers.

With wireless local area networks (WLAN), applications such as internet access and file sharing can now be implemented with new levels of freedom and flexibility. WiFi supports true multipoint networking with such data type broadcast, multicast, and unicast packets. The media access control (MAC) address built into every device allows a virtually unlimited number of devices to be active in a given network. These devices contend for access to the airwaves using a scheme called carrier sense multiple access with collision avoidance (CSMA/CA).

Wireless communication systems use one or more carrier frequencies to communicate. Both WiFi and Bluetooth share the same 2.4 GHz band, which extends from 2.4 GHz to 2.4835 GHz. A system can use one of two methods to transmit in this band, both are digital spread-spectrum service (DSSS) techniques. Frequency-hopping spread-spectrum enables a device to transmit high energy in a relatively narrow band but only for a limited time. Alternatively DSSS allows a device to occupy a wider bandwidth with relatively low energy in a given segment of the band, and it does not hop frequencies. WiFi uses DSSS, using a 22 MHz of bandwidth to transmit data with speeds of up to 11 Mbps. A WiFi system can use any of eleven 22 MHz wide sub-channels across the allocated 83.5 MHz of the 2.4 GHz frequency band. A maximum of three WiFi networks can coexist without interfering with one another.

The WiFi MAC layer, which is based on the Ethernet protocol, assumes that many stations share the same medium and therefore if a transmission fails, it is because two WiFi stations tried to transmit at the same time. The MAC layer is where the data rates are determined and is the place to resolve data-rate versus packet-size tradeoffs. Because the MAC layer comprises digital hardware and software, techniques employed there tend to be relatively inexpensive to implement.

A disadvantage of using WiFi is that it uses the 2.4 GHz spectrum, which is crowded with other devices such as Bluetooth enabled devices, microwave ovens, cordless phones, or video sender devices, among many others. Although not experienced in the tests that were carried out, this may cause degradation in performance. Other devices which use microwave frequencies such as certain types of mobile phones can also cause degradation in performance. Obvious restrictions of WiFi technology include physical limitations, such as distance and tangible obstacles that affect wireless communications. While the maximum effective range of a WiFi access point can be 50-70 metres depending on the IEEE wireless standard (802.11a/b/g) being used, such ranges are seldom achieved. Even a simple brick wall can effectively eliminate the signal indoors; trees or buildings can also severely degrade the signal outside. Based on research done by Intel, Table 3 shows the range of signal strengths, in a WiFi environment, for common physical objects. The ability of radio waves to transmit and receive information, as well as speed of transmission, is affected by the nature of any obstructions in the signal path. Actual signal achieved over a distance will vary widely with each installation, but will be less than the maximum rated range. Note that this signal degradation differs from the signal lost from interference noted above in that it reflects the optional physical characteristics of the 802.11 standard.

Obstruction	**Signal Strength**	**Example**
Open Space	None	cafe, garden, sports oval
Wood	Low	interior wall, floor, door
Glass	Low	window, coffee table, desk
Bricks	Medium	exterior/interior walls, floor
Concrete	High	exterior wall, support column
Metal	Very High	desk, filing cabinet, elevator

Table 1. Signal strength for common physical objects. **(Source:** Intel Wireless Research**)**

2 System Tests

2.1 SYSTEM COMPONENTS

The mobile device used in the tests is the iMate PDA2k. The device satisfies the communication requirements for the mobile-computing based construction defect application as well as being highly portable, e.g., “pocket-sized.” The application requires that the device supports a variety of wireless communication protocols such as GPRS and WiFi and contain an expansion slot for the GPS receiver. Additionally the mobile device must be able to capture digital media (audio, photo and video). The iMate PDA2k does not have any inbuilt GPS capabilities; however, the device has a secure digital input/output (SDIO) card slot for the GPS receiver.

The operating system for the iMate PDA2k is Windows Pocket PC 2003 Second Edition. The application is written in Java 2, Micro Edition (J2ME). The IBM J9 J2ME version 5.7.2 runtime environment was installed to support the J2ME implementation of the application. J2ME was selected as the programming language for the application given its cross platform portability. The basic J2ME classes support HTTP. Data transmission using any other protocol requires additional Java Specification Request (JSR) packages. The JSR packages extend the capability of the J2ME to include support for other wireless communication protocols such as Bluetooth and wireless application protocols such as MMS. Presently there is no J2ME enabled mobile device that supports all JSR packages. As such, the current application only supports the transfer of construction defect data packaged in an HTTP message which is transmitted over WiFi and GPRS. Ideally, the application should also support data transmission via MMS, which can also be sent over GPRS or WiFi. However, the total data size of HTTP messages is similar to MMS messages when the message overhead is included (e.g., message headers). Thus, the results for testing HTTP messages would be similar to MMS, providing an indication as to the suitability of MMS messages as another way to transmit construction defect data.

The GPRS tests were conducted using the Telstra network for data transmission. The Telstra network was chosen over other service providers as Telstra support the iMate PDA2k and has better competitive pricing options in using their GPRS services. Each time a connection is made to the Telstra network, there is a 22c connection fee. A connection is normally made only once per day or if the device is reset. Once a connection is established, a rate of 2.2c is charged per kilobit that is downloaded or uploaded. Web browsing using the Telstra Web proxy incurs a 55c fee per 25kb block. This application bypasses the Telstra Web proxy.

The WiFi tests are conducted using an Apple AirPort Extreme base station which uses the 802.11g IEEE wireless standard but has compatible 802.11b/g modes to support 802.11b devices. The AirPort is extremely secure and is equipped with a built-in firewall to help prevent unwanted access to data. Additionally it is certified for WiFi Protected Access (WPA), which greatly increases over-the-air data protection and access control on wireless networks.

2.2 TEST PROCEDURE

The procedure for conducting the tests is to attach and send an image (640x480) of various file sizes ranging from 30kB to 300kB (Figure 1) using the J2ME application form. Three tests are conducted for each file size; the average transmission time is then calculated. The data sent by the mobile device is received by a computer which listens for the data from the mobile device. The service listeners include an SMS/MMS service gateway server and an HTTP daemon. The daemon runs continuously and exists for the purpose of handling periodic service requests the computer expects to receive from the mobile device.

30 kB Image

300 kB Image

Figure 1. The various image file sizes used in the test procedure.

A *time sent* alert displays the sent time on the mobile device and subsequently a *time received* message displays on the server after the form transmission is successful. Both times are recorded and inserted into a spreadsheet to calculate the data for time elapsed and data speeds for each test per file size transmission. All GPRS tests are conducted indoors in an office where the signal strength ranges between tests from “very good” to “excellent.” All WiFi tests are conducted indoors as well and the signal strength for all tests are “excellent.” The tests conducted using WiFi are carried out at the same physical location with the wireless base station within a 2 metre radius of the mobile device.

Each time a test is conducted, for both GPRS and WiFi, a “time sync” is performed between server and mobile device. The time difference between the mobile device and the server fluctuates significantly, sometimes by a minute. By synchronizing the time between the mobile device and the server, more accurate data transmissions times are recorded.

3 Test Results

3.1 HTTP OVER GPRS DATA THROUGHPUT

Table 1 and Figure 2 report the data transfer for HTTP over GPRS. We were unable to achieve the theoretical limit of throughput over GPRS. Based on the tests performed and the data obtained, the average expected speed of data transfer of 9-13 kbps. The calculations were made using the following equation:

Equation:	**Example:**
Image Size x (1024 bytes / 1 kilobyte)	300 kB x 1024/1
= (value) x (8 bits / 1 byte)	= 307 200 bytes x (8/1)
= (value) / elapsed time in seconds	= 2 457 600 bits / 181 sec
= (value) x 1/1000	= 13 577.900 bps x 1/1000
= (value) kbps	= 13.58 kbps

Image File Size	Test 1	Test 2	Test 3	Average
30 kB	10.69	12.93	12.93	12.18
50 kB	7.19	10.78	9.31	9.09
100 kB	9.10	9.20	9.64	9.31
150 kB	12.54	11.93	13.07	12.51
200 kB	9.99	9.58	10.44	10.00
300 kB	13.28	10.11	11.22	11.54

Table 2.HTTP Over GPRS Data Throughput Speeds (kbps)

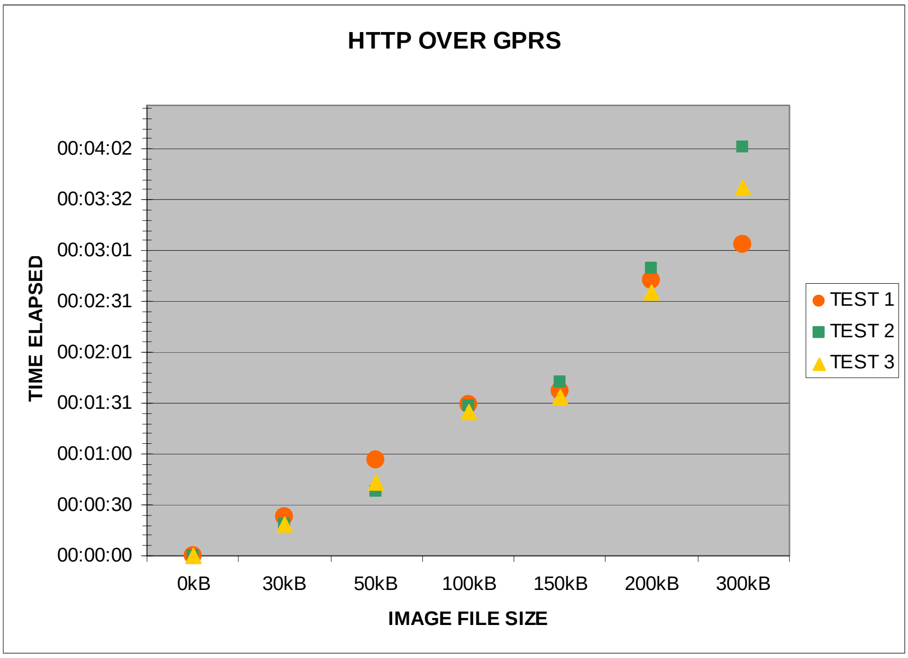

Figure 2. HTTP Over GPRS – Time Elapsed in Sending and Receiving Files

Figure 2 shows an almost linear increase in data transmission time as the image file size increases. When comparing the average time elapsed for the 100kB, 200kB and 300kB, there is a trend of approximately 50-70 seconds between each 100kB increments. There is no evidence to suggest any fluctuation in times due to the varying GPRS signal strength and Telstra mobile network load.

When the tests were conducted, knowledge of the class of GPRS communication was unknown to the testers. However, the results produced – an average transfer rate of 9-13 kbps – suggest the timeslots are set at 4+1 (sending rate of 8-12kbps). The reality is mobile networks are always likely to have lower data transmission speeds than fixed networks.

3.2 HTTP OVER WIFI DATA THROUGHPUT

The results for data transmission for HTTP over WiFi are depicted in Table 2 and Figure 3. Using the tests and the data obtained, calculations were made to find out the speed of data transfer in minutes and seconds. The average rate of transfer at 190-410 kbps is significantly higher than GPRS, but well short of the reported 802.11b standard of 11 Mbps. The same equation used to calculate GPRS rates is used to calculate the WiFi rates of transfer. Figure 3 shows that as we increase in file size, the elapsed time is consistently increasing, apparently as a second-order polynomial. Evidence of this is seen when comparing the 150 kB image to the 300kB image. The

150 kB image requires an average of approximately 4 seconds to transmit. By doubling the image file size to 300 kB, theoretically the transmission time should be approximately 8 seconds. However, this is not true as the average elapsed time for the 300 kB file across the 3 tests is approximately 13 seconds. An error rate of +/- 1 second is calculated for all the tests using HTTP over WiFi.

Image File Size	Test 1	Test 2	Test 3	Average
30 kB	245.76	245.76	245.76	245.76
50 kB	409.60	204.80	204.80	273.07
100 kB	409.60	409.60	409.60	409.60
150 kB	307.20	245.76	409.60	320.85
200 kB	204.80	234.06	273.07	237.31
300 kB	175.54	189.05	204.80	189.90

Table 3. HTTP Over WiFi Data Throughput Speeds (kbps)

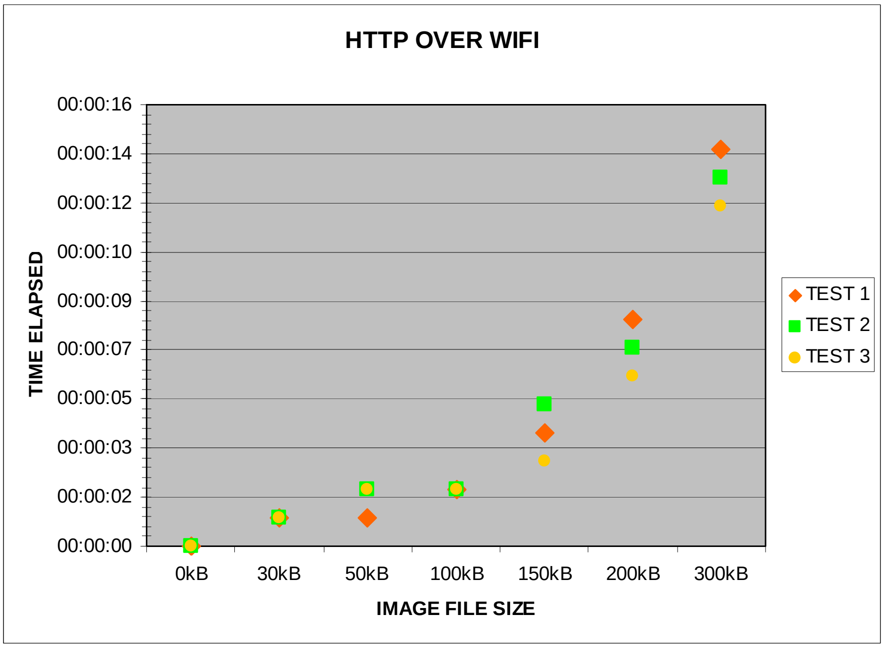

Figure 3. HTTP Over WiFi – Time Elapsed in Sending and Receiving Files

4 Conclusion

This report presents the results of data throughput rates for wireless communication using HTTP over GPRS and WiFi on a mobile device through a custom-built application for construction defect reporting. The study focused on measuring the time to send messages of varying sizes wherein the messages contained data about the construction defects. The data included a digital image of the defect, the GPS coordinates of the defect, and additional textual meta data about the defect. The data transmission studies show that if GPRS is the method of wireless connectivity, then the recommended maximum size of the digital image is approximately 50kB with a throughput of 9-13kbps. Image sizes greater than 50kB would require the user to wait more than one minute to transfer the image, which we believe could have the unintended side-effect of causing the end-user to believe that the image is not transmitting correctly. If WiFi is available, then image size is not an issue.

A noticeable problem occurred when conducting the 3 WiFi tests. The power consumption by the iMate PDA2k when WiFi connection is active is high, making battery life a concern.

Data security is an issue for both protocols, but more so for GPRS. WiFi commonly uses Wired Equivalent Privacy (WEP) protocol for protection, which has been shown to be easily 'hackable' even when properly configured. Newer wireless solutions are slowly providing support for the superior WiFi protected access protocols, though many systems still employ WEP.

The results of the study show that the throughput rate available over GPRS is highly variable and can degrade, depending upon the radio conditions. GPRS, like other radio-based wireless protocols, exhibits many of the following characteristics of low bandwidth, high and variable latency, and rapid bandwidth fluctuations over time. In comparison with GPRS, WiFi is significantly faster in both transmission and bandwidth rates. While these benefits to WiFi are important in our testing, the wireless communication protocol WiFi susceptible to saturation and signal jamming. Interference from similar radio frequencies can cause additional problems.

Based on the results, the study concludes that a mobile computing based construction defect management application is feasible given the type of data that would be transferred and the available data transmission rates. However, the resolution of the digital image of the defect should be considered in light of the available wireless communication link. The user should capture only what is necessary to depict the defect.

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