Analysis of Transport Protocols in Hybrid Networks

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Abstract

Accessing data services through digital cellular networks is becoming something common. Such networks are based on wireless technologies, which were ignored when the classic communication protocols were designed. As many authors have noted, the TCP transport protocol shows an inefficient behavior when running over wireless links. Several solutions have been proposed to correct this problem. We propose a simple solution based on the indirect model of communication and the substitution of TCP. Several experiments have been realized, using a network simulator (ns: UCB/LBNL Network Simulator). The results of these experiments let us conclude that the use of indirect connections using an specific transport protocol instead of TCP over the wireless part of the connection increases the performance of communications.

Preface

This paper is a summary of the final year project[Lluch Lafuente, 1999] realized by the author as an essential part of the study in Computer Science at the University of the Basque Country. The project is closely related with research done by Jos Miguel Alonso, which was the director of the project, and Jos Mara Rivanedeyra, both members of the Department of Computer Architecture and Technology of the University of the Basque Country. Some of the results of the project have been used by Jos Mara Rivanedeyra for his dissertation [Rivanedeyra, 2000]. Note that due to improvements realized after the project's end, the experimental results may differ from the original documentation.

1 Introduction

Accessing data services through digital cellular networks is becoming something common and attractive. For example, one can connect his laptop with Internet with the use of a mobile phone. GSM is a popular digital cellular telephony system, but it offers a poor quality for such kind of services (data access was a secondary target when the standard was defined). J. M. Rivanedeyra and J.M. Alonso detected on of the reasons of the poor performance in the architecture of the these scenarios and proposed an alternative communication architecture. It was decided to validate the solution first by simulation, and then by implementation.

The main objective of the project was to realize several experiments with the network simulator ns: UCB/LBNL Network Simulator, that validate a set of alternatives to the actual system used to access Internet through GSM. To reach this objective several tasks were done: study of the network simulator, study of hybrid environments (those in which wired and wireless technologies are involved), extension of the simulator for the experiments, modeling of the architectures, and finally the experiments.

Section 2 gives a brief description of what was done in order to study the network simulator. Section 3 and 4 summarize respectively the work done for studying hybrid environments and modifying the network simulator. Section 5 presents the experiments realized and their results. The last section contains the conclusions.

2 ns: UCB/LBLN Network Simulator

ns: UCB/LBLN Network Simulator [Network Research Group, 1998] is a discrete event simulator targeted at networking research that provides substantial support for simulation of TCP, routing, and multicast protocols. It is object oriented, written in C++, with an OTcl interpreter as front-end. One of the objectives of the project was to familiarize with this network simulator. In order to accomplish with this objective, several documents were written: a report of the installation, a user manual, a programmer manual and a document that present a basic set of examples[Lluch Lafuente, 1999].

3 Accessing Internet through GSM

A new environment of data communication, emerged due to the even more common use of laptops and cellular digital telephone networks, is becoming important: the use of the data services that such networks provide to access information servers typically located in Internet. This new environment is based on wireless technology, in opposition to the traditional networks.

The concept of nomad user arises. Such kind of user can change his location while keeping connected to the network requesting different information services. This is one of the advantages of the wireless networks: the ubiquity. In addition, mobility is managed and controlled by the network, making it transparent to the applications and communications protocols.

These characteristics suppose an advantage of this kind of access over others, but there is a price to pay. Wireless links of cellular networks have different characteristics from wired links used on fixed networks. While wired links have satisfactory bandwidth, short constant delays, and a low error rate, wireless links are a poor resource: they have low bandwidth, long delays and a big error rate.

Such kind of links was ignored when the classic communication protocols (the TCP/IP architecture) were defined. Several authors have shown that there is a problem of performance when using TCP over networks based on wireless technology. Fine adjusted for fixed networks, the congestion control mechanism of TCP does not have an adequate behavior over wireless networks. These mechanisms interpret the long delays of the wireless links as a problem of congestion, and act starting correction mechanisms to alleviate a congestion that does not exist. The consequence is a reduction of the data flow, wasting the scarce avaliable bandwidth.

The are several studies that have take care of this problem. In this paper, the problem is focused on the particular case of accessing Internet through GSM networks, proposing alternatives to the actual architecture, which should perform better.

3.1 GSM. Data Service

GSM is a pan-european standard of cellular digital telephony used mainly in european networks. The use of GSM is growing fast in the rest of the world, especially in Asia and Australia. This standard, in addition to the telephone service, defines data transmission too, but it was at first a secondary target. Although, several estimations show that in the year 2000 the half of the traffic of this networks will be data [Rivanedeyra et al., 1998a].

Nowadays, the service this kind of system offers is fairly poor: circuit-switched connections with a nominal bandwidth of 9.6 Kbps, which in the best case is reduced to 7 Kbps [Alanko et al., 1994]. New parts of the GSM standard are being developed (HSCSD and GPRS) in order to obtain better transmission rates, but the day at which they will be used remains still distant. It is possible too, to obtain better transmission rates by using full digital connections (connection from GSM to ISDN) and data compression, but the use of PSTN when accessing Internet is more common at the moment and, in addition, the problem of low efficiency remains. In addition to all that, propagation delays and the bit error rate are really big. Packet losses or error connections, are mainly caused by wireless link failures and user mobility [Cceres et al., 1995], and rarely by network congestion.

3.2 Architecture

Conventional access to Internet using GSM networks is shown in Figure 1. The mobile node connects to the GSM network using a mobile phone that has a card that emulates a modem, so that classic software

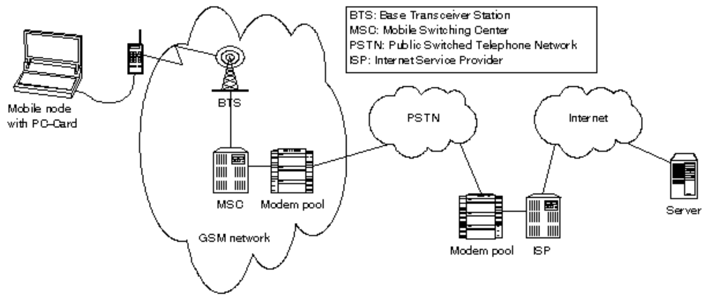

Figure 1: Scenario for a conventional access to Internet through GSM

can still be used. The connection from user to server has to pass through three networks. First, the GSM network, in which a modem pool located in the MSC (Mobile Switching Center) allows to connect to the ISP (Internet Service Provider) through the second network: the PSTN (Public Switched Telephone Network). Finally, the ISP establishes the connection with the information server in Internet.

The difference between that kind of Internet access and the classic ones, is the use of the GSM network. It limits the bandwidth to 9.6 Kbps, while delay and bit error rate depend on the bearer service mode chosen. There are to modes that GSM networks offer to access data: transparent mode and non-transparent mode. When using the transparent mode, which follows the ISDN V.110 specification, the bit error rate is about 10^3, while delay remains constant. When using the non-transparent mode, the use of an error correction protocol called RLP (Radio Link Protocol), makes the bit error rate descend to 10^8, but as consequence, delays becomes longer and both bandwidth and delay become variable, especially when the link conditions are poor. The present study is focused on this mode. The protocol stack used in this situation is shown in Figure 2.

It can be observed how the RLP protocol is used between the mobile node and the MSC, while a standard modem protocol is used to connect the MSC with the ISP. The PPP protocol is used to manage the link between the mobile node and the ISP. This protocol can be used whenever the IP address is dynamically or statically assigned. In the last case, the SLIP (Serial Line IP) protocol or his compressed version (CSLIP) could be used instead of PPP. The rest of the protocols are the commonly used in TCP/IP environments.

It is really interesting the existence of two worlds based on different technologies (wired and wireless), and the use of a transport protocol (TCP) managing the connection, which passes through these two worlds. Due to reasons that will be said later, the ISP will be the element that

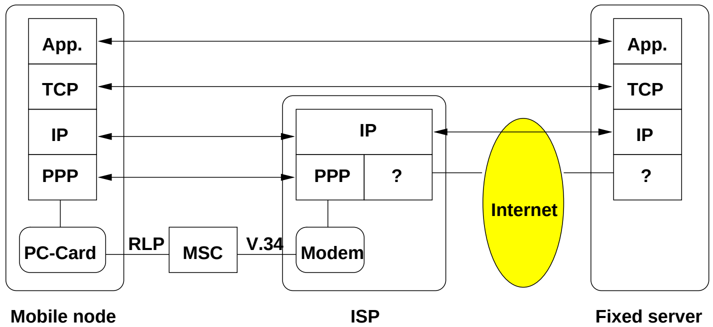

Figure 2: Actual protocol architecture

separates the two worlds, located not between the wired world and wireless world, but between the GSM network and the Internet. In any case, the interesting thing is that a protocol designed to be used over wired links is used to manage connections that implicates wired and wireless links, and that this fact causes low performance problems.

3.3 Problems of using TCP over wireless links

TCP is the standard transport layer protocol in Internet. It provides a reliable connection-oriented transport service to the application layer. To guarantee this service, TCP implementations counts on various mechanisms.

To ensure the delivering of segments (interchange unit between transport layer entities), TCP uses acknowledgments (acks) and retransmissions. Segments not acknowledged have to be retransmitted. The congestion of the network can provoke the discard of the sent segment or the ack. It is a nonsense to wait indefinitely the arrival of a segment's ack, so timers are used by congestion control mechanisms to diagnostic the congestion problem and act in consequence. When a segment is sent, a timer is activated. When it triggers, TCP considers that the segment is lost and deduce that the cause is the network congestion, because that is the main cause of losses in wired networks. The slow-start and Karn algorithms are then activated, provoking the reduction of the data flow and the value of the timers, in order to alleviate the congestion of the network.

Between the mobile node and the ISP there is a PPP link (free of congestion), but there are long and variable delays. TCP interprets these delays as losses caused by congestion and activates the unnecessary congestion control mechanisms. The data flow is then drastically reduced and the poor bandwidth is used in a less efficient manner.

In sum, the congestion control mechanism of TCP reduces the perfor-

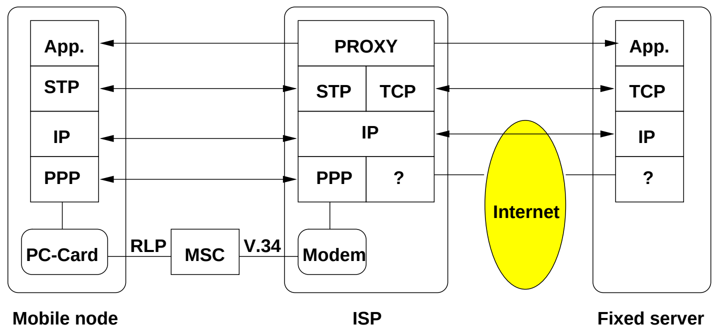

Figure 3: Proposed protocol architecture

mance in wireless environments. In addition, other TCP characteristics, like the use of redundant headers, contribute to the inefficient use of the poor bandwidth of the wireless links.

3.4 Project Proposals

One of the objectives of the project is to validate the ideas presented in [Rivanedeyra et al., 1998a] and [Rivanederyra et al., 1998b]. The alternative to the actual architecture of Internet access through GSM presented in these articles is based on two basic ideas: use of indirect model and substitution of TCP.

3.4.1 Indirect Model

The idea of using the indirect model of communication, at transport level, consists on splitting connections in parts so that every connection is managed independently and elements located between the parts coordinate them. The advantages arise when every part of the connection occurs over an environment of different nature than the others, because in that manner it is possible to manage specifically every part in order to achieve a better performance.

Unfortunately, there are some disadvantages: the end-to-end semantic of connections is lost and there is an overhead introduced by the intermediators. To know the consequences of this, think that with the use of TCP the sender will receive acks from the intermediary and not from the receiver. So, the sender will not really know in which moment the receiver has definitely received the data.

When using this kind of systems, there are two important design aspects: how to divide the connections, and which functions will realize the intermediaries. As in [Rivanedeyra et al., 1998a] and [Rivanederyra et al., 1998b], the intermediary is located in a node called GSN (Gateway Support Node).

This node is a part of the GSM network and could realize additional functions of ISP, giving an added value to the GSM operator. The communication is divided in two worlds: the GSM network and the Internet. The protocol architecture is shown in Figure 3.

The main difference with the actual system, apart from the use of the indirect model, is the presence of a new protocol called STP that substitutes TCP in the mobile part of the connection. This protocol is described later. In the intermediary, and at application layer, there are set of programs called filters. These filters are also known as the Proxy and are responsible to coordinate both parts of the connections. At first, the Proxy will act as a relay. Additional functions this entity can realize are selective dropping of superfluous header information, delay data for later pickup, re-segmentation of data, reducing *frivolous* traffic addressed to the mobile host, etc [Rivanedeyra et al., 1998a].

3.4.2 Simple Transfer Protocol

The previous proposal succeeds in isolating the problems in the mobile part. These problems, are caused by the inappropriate use of TCP in wireless environments, and consist in an inefficient use of the low bandwidth.

As second improvement, the substitution of TCP is proposed. The new protocol should be designed specifically to run over the mobile part of the connection as efficient as possible. The proposed name is Simple Transport Protocol (STP). It should have characteristics such as reduced headers and a flow control tailored to the characteristics of the links. It will not include neither congestion control nor error control (the use of RLP guarantees the absence of errors between the PC-card and the MSC and another protocol runs between the MSC and the Modem at the ISP).

Independently of the characteristics of the new transport protocol, introducing it in the system require changes only in clients (mobile nodes) and the GSM networks, and not in servers (Internet hosts). Changes in clients can be as simple as changes in libraries that implement the transport service (typically sockets).

4 Extension of the Network Simulator and Modeling of the Architectures

The network simulator ns does not allow to simulate the situations described in the previous section. To model these situations, various elements have been designed, implemented and integrated in ns. These elements are basically links, applications, and protocols. The implementation required in some cases the introduction of new code or, in other cases, the modification of the existing code. This section presents a description of these elements, ignoring when possible all reference to implementation details.

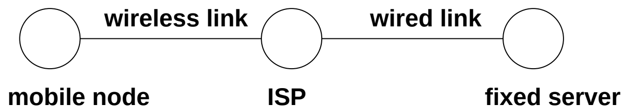

Figure 4: Network Topology Model

4.1 Links

The topology of environments in which clients access Internet servers through GSM can be model in a very simple way (see Figure 4). Three nodes (mobile node, ISP and fixed server) and two links: wireless link and wired link. The wireless link connects the node representing the client and the node representing the ISP, while the wired one connects this node with the fixed server.

Wired link This link represents all the links in the communication between the ISP and the fixed server in Internet. In the real world the path between ISP and Server implies many links, that are, in general, reliable and fast. Several probes have been realized to determine the values of bandwidth and delay of the wired link. Finally, the values of 100 Kbps and 100 ms were chosen. Congestion or link failures will be ignored.

Wireless link This link represents the link that connects mobile node and ISP. The characteristics of such link in a GSM Network are 9.6 Kbps and a long and variable delay (supposing the use of the non-transparent mode).

Following [Nguyen et al., 1996], the link has been modeled as something similar to a Markov model with two states: an error-free state (stae L) and an error state (state E). Such model is possible because it is known that the errors are bursty. In opposition to [Nguyen et al., 1996], where the time to stay in a state is modeled with transition probabilities, here the time to stay in a state is modeled with random distributions. Figure 5 illustrates the model.

Exponential distributions model the duration time of each state. In state E the average value of the distribution is t_E, while in state L the average will be t_L. The delay in state L is modeled with a constant distribution with value r_L, and in state E the delay is modeled with an uniform distribution between a_m y a_M.

For the experiments, the values of the variables was: $t_L = 50s$, $t_E = 10s$, $r_L = 400ms$, $a_m = r_L$, $a_M = 6r_L$. This values are based in some studies (like [Alanko et al., 1994]).

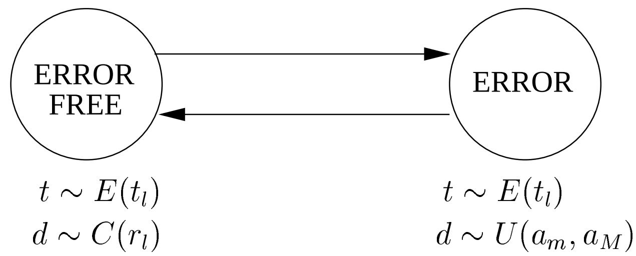

Figure 5: Wireless Link Model

4.2 Applications

Three different kind of communications were considered to be simulated in the experiments. Their are based on the use of three mostly used Internet applications: telnet, ftp and WWW.

Telnet Telnet communications use a unique transport connection. Their characteristics are short messages, with variable intervals between messages. The telnet client will be located at the mobile node, while the telnet server will be placed in then fixed server. The network simulator used does not provide an adequate telnet implementation. A better modeling and implementation was necessary. Two type of new Application entities were implemented: a Telnet Client and a Telnet Server. The client sends the server a request message of a given small size. The server answers immediately after the arrival of the message with a response message of a given medium size. The client then sends a new request after some given time when it receives the servers's response. The size of the request and response messages and the time the client wait after sending the new message are modeled as exponential distributions.

FTP A ftp communication occurs over a unique transport connection. The fixed server will act as ftp server, while the ftp client will be placed in the mobile node. The network simulator ns provides a satisfactory implementation of ftp (modeled as a bulk data transfer). Although, several modifications were done to adapt its behavior to the needs.

WWW A WWW communication implies the existence of several transport connections. Every request of the WWW client (located at the mobile node) requires a connection, while answers from the WWW server (located at the fixed server) can consist on various connections (a connection for each component of the requested web page).

There exists a WWW application in ns, but it was not adequate for the experiments. An alternative application [Henderson et al., 1998a] was chosen, modifying its implementation to adapt it to the needs. This application is a http traffic generator based on a study about http traffic patterns made by Bruce Mah [Mah, 1997].

4.3 The Proxy

This element has been implemented as an application that acts as a relay between two transport connections. The proxy receives data from one part of a connection and sends it through the other. When a connection is closed in one of the parts, the proxy closes the other part of the connection. The proxy has no latency (he sends as soon as he receives the data) and unlimited capacity (a relatively infinite buffer).

4.4 TCP

There are several implementations of TCP in ns. A bidirectional implementation of Tahoe TCP was chosen, fixing two parameters: the initial credit and the maximum segment size. The chosen value for the initial credit was 8192, observed in several TCP connections made by FTP. The maximum segment size was fixed to 1460 bytes: observed Ethernet datagrams over PPP implementations occupy 1500 bytes, and 40 bytes from the TCP/IP header must be subtracted.

4.5 STP

The new transport protocol STP should provide a reliable connection-oriented transport service, and its behavior must be tailored to the characteristics of the wireless link.

It has been implemented including following functions: segmentation/reassembling of segments, opening/closing connections and flow control. In addition it uses reduced headers. It does not include neither control congestion nor error control.

The header contains information about source and destination ports, opening/closing connections, sequence numbers and acknowledgments. For the segmentation it uses a maximum segment size of 1472 bytes, cause the STP/IP header has a size of 28 bytes (1500 bytes of the datagram - 28 bytes of the header = 1472 bytes). Flow control is done by a sliding window algorithm without retransmissions. The initial credit is fixed with 8192 bytes.

4.6 Measure parameters and mechanisms

Two measure parameters have been used in the experiments: goodput and throughput (both at the transport layer).

Throughput is the measure of how soon an end user is able to receive data. It is determined as the ration of the total data received by the end user and the connection time. The throughput directly impacts the user's perception of the quality of service.

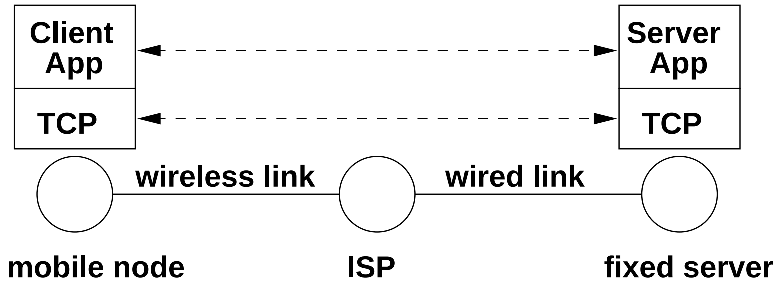

Figure 6: Model of the end-to-end TCP architecture

Goodput is the measure of how efficiently a connection utilizes the network. It is determined as the ratio of useful data received at the destination and the amount of data transmitted by the source. If a connection requires a lot of extra packets to traverse the network due to retransmissions, its goodput is low. It is desirable that each connection has a high goodput. This metric is clearly is of great significance for efficient operation of a network [Bakshi et al., 1995].

Several modifications in the code of ns have been performed to implement mechanism that permits collect these two parameters.

5 Experimental results

This section presents the various experiments realized in order to validate the ideas discussed in section 3. A first set of experiments tries to probe the problems of the actual architecture used for accessing fixed networks (Internet) through mobile networks (GSM). Then the effects of new architecture are probed, studying the individual effects of the two techniques the proposed architecture are based on, and the overall effects of the new architecture.

The experiments have been realized using the network simulator ns, which have been modified to allow model the real situations. The topology of the network is very simple (see Figure 6. It consists on three nodes (mobile node, ISP and fixed server) and two links (wired and wireless). The wired link connects the mobile node with the ISP, while the wireless link connects the ISP with the fixed server. These elements have been described in the previous section.

5.1 Effects of Variability of the Delay

The objective of this first set of experiments is to verify that the variability of the wireless link delay causes a considerable loss of performance due to the inadequate behavior of TCP.

	1 KB	10 KB	100 KB	1 MB	telnet	WWW
constant delay	2.22	6.46	8.94	9.30	1.77	1.16
variable delay	2.10	5.97	8.77	9.27	1.54	1.13

Table 1: Effects of variability on the throughput

	1 KB	10 KB	100 KB	1 MB	telnet	WWW
constant delay	0.76	0.92	0.95	0.95	0.83	0.62
variable delay	0.74	0.89	0.94	0.95	0.79	0.60

Table 2: Effects of variability on the goodput

The actual architecture (see Figure 2 for the protocol stack and Figure 6 for the model), i.e. end-to-end TCP connections has been probed under two situations: a hypothetical situation in which the delay of the wireless link remains constant and the *real* situation (where the delay is variable). Tables 1 and 2 present respectively the values of goodput and throughput measured in various types of communication under the two situations (constant delay and variable delay). The different type of communications are ftp, telnet and WWW. The first one has been probed with different file sizes.

The values of throughput in this comparison are not as important as the goodput values, since the variability in the wireless link delay increases the average delay, making the throughput descend. Hence, the interesting parameter is the goodput. This parameter shows the efficiency in the use of links. The goodput in the real situation (variable delay) is lower than in the hypothetical situation (constant delay). This specially true in the case of telnet and in the transmission of short files. When the size of the transmitted file grows the loss in the goodput tends to minimize.

Since the architecture (end-to-end TCP connections) is the same in both situations, we must conclude that the reason for which the goodput descends is the existence of retransmissions. But the links have neither congestion nor failures that could provoke these retransmissions. The congestion control mechanism of TCP is not reacting good in the presence of variability in the wireless link delay. The consequence is an inefficient use of the links reflected in the descent of the measured goodput. However for large file transmissions the descent in the goodput tends to minimize. The reason is that the congestion control mechanism is adaptative and succeeds in finding good values for the retransmission timers that avoid unnecessary retransmission. This is true in the case ftp where data is transmitted in one connection, but not in the case of telnet and WWW because these types of communication require many connections in which the timers are reset (a possible solution is to maintain and use statistics of previous connections [Padmanabhan et al., 1998]).

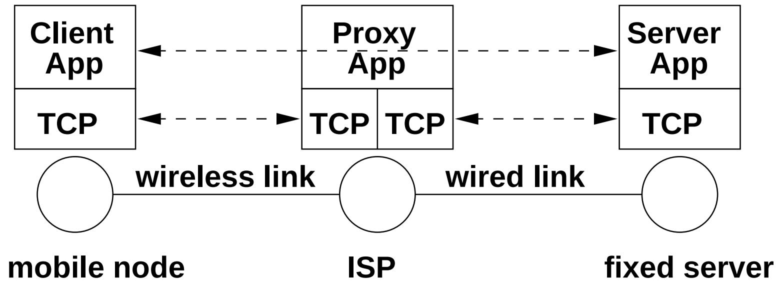

Figure 7: Model of the indirect TCP architecture

	1 KB	10 KB	100 KB	1 MB	telnet	WWW
end-to-end	2.10	5.97	8.77	9.27	1.54	1.13
indirect	2.20	6.10	8.77	9.27	1.54	1.21

Table 3: Effects of the indirect model on the throughput

As conclusion of these set of experiments we can say that a variable delay in the wireless link has a negative effect on performance.

5.2 Effects of the Indirect Model

The objective of these set of experiments is to verify the goodness of the indirect model. The network presented in Figure have been probed using two different architectures: the actual architecture (end-to-end TCP connections) and an architecture based on the indirect model (see Figure 7).

Connections in the indirect architecture are splitten in two TCP connections: one between client and proxy and another between proxy and server. The proxy is located at the ISP node, while client and server applications are respectively located at the mobile node and the fixed server node.

Table 4 is very interesting. It presents the measured goodput values. In the case of the actual architecture goodput has been measured in the

	1 KB	10 KB	100 KB	1 MB	telnet	WWW
end-to-end	0.74	0.89	0.94	0.95	0.79	0.60
wired	0.76	0.92	0.95	0.95	0.83	0.70
wireless	0.73	0.88	0.93	0.95	0.75	0.64

Table 4: Effects of the indirect model on the goodput

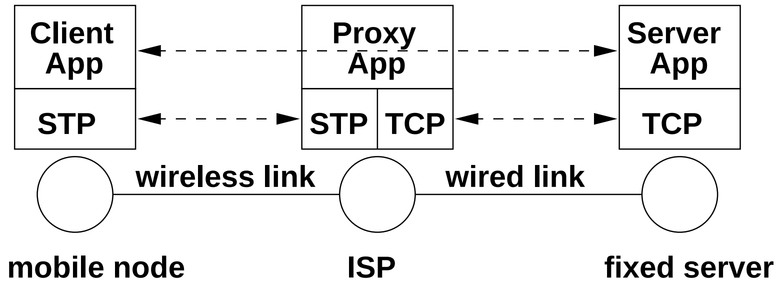

Figure 8: Model of the proposed architecture

	1 KB	10 KB	100 KB	1 MB	telnet	WWW
TCP	2.20	6.10	8.77	9.27	1.54	1.21
STP	3.17	7.71	9.18	9.36	1.56	1.32

Table 5: Effects of STP on throughput

end-to-end connection (end-to-end). In the case of the architecture based on the indirect model two goodputs have been measured: the goodput in the wireless link (connection between mobile client and proxy) and the goodput in the wired link (connection between proxy and fixed server). The goodput in the wired link is always better or equal than in the wireless link. That confirms that the inefficiency problems are located in the wireless link. The values of Table 4 do not let us conclude which architecture uses the links in a more efficient manner. Tables 3 shows that the indirect architecture achieves a better throughput in the case of short ftp transmissions and WWW communications. This is a good result, but the best thing is that we have confirm the location of performance problems and isolated it.

5.3 Effects of the Substitution of TCP

The objective of these set of experiments is to verify that the substitution of TCP by a transport protocol that does not include congestion control, improves the performance of the communications.

Two architectures have been confronted. In both of them indirect communications are used. The first architecture uses TCP as transport protocol in both sides (client-proxy and proxy-server) of the indirect communications. The second architecture (see Figure 3 for the protocol stack and Figure 8 for the model) uses STP as transport protocol of the mobile side (client-proxy). The main difference between STP and TCP is that STP does not perform congestion control and has a reduced header.

As shown in Table 6, STP uses the wireless link in a more efficient

Table 6. Effects of STP on wireless goodput

	1 KB	10 KB	100 KB	1 MB	telnet	WWW
TCP	0.73	0.88	0.93	0.95	0.75	0.64
STP	0.92	0.97	0.97	0.97	0.91	0.95

Table 6: Effects of STP on goodput

Scene	1 KB	10 KB	100 KB	1 MB	telnet	WWW
TCP	2.10	5.97	8.77	9.27	1.54	1.13
NEW	3.17	7.71	9.18	9.36	1.56	1.32

Table 7: Old Architecture vs New Architecture: Throughput

manner than TCP. In addition the goodput obtained by STP is more stable. The consequences are a very notable increase in the throughput (see 5). The advantage of avoiding the congestion control mechanism are now clear.

5.4 Overall Effects of the New Architecture

We present here the overall effects of the new architecture, confronting the results of the experiments based on the proposed architecture (indirect connections with substitution of TCP in the mobile part) with the results of the experiments based on the actual architecture (end-to-end connections).

As shown in 8, the new architecture uses the resources (links) in a more efficiently way than the actual architecture. The consequence is an increase in the performance of the communications.

5.5 Conclusions of the Experiments

The results of the experiments confirm that the wireless link delay variability is cause of performance loss when accessing wired networks through wireless networks.

Scene	1 KB	10 KB	100 KB	1 MB	telnet	WWW
end-to-end	0.74	0.89	0.94	0.95	0.79	0.62
wired	0.76	0.92	0.95	0.95	0.83	0.70
wireless	0.92	0.97	0.97	0.95	0.91	0.95

Table 8: Old Architecture vs New Architecture: Goodput

The new architecture improves performance of all type of communications (ftp, telnet and WWW). The main cause of performance improve is that the protocol that substitutes TCP (STP) uses more efficiently the wireless link, since it is designed specifically to work over it. Note that the behavior of the new transport protocol is highly stable; the values of wireless goodput are always over 0.9. The results of the experiments seem to validate the ideas exposed in section 3.

6 Conclusions

Many research groups have studied traditional transport protocol behavior over hybrid networks. They all conclude that the use of end-to-end TCP connections offers a poor performance when working with wireless links, and propose different alternatives. In this paper the alternative of the project have been presented. This alternative is based on two basic ideas: use of the indirect model and substitution of TCP.

The inefficiency problems when using the actual system and the benefits of the proposed alternative have been validated by several experiments realized with ns. This network simulator has been modified, introducing new elements and modifying existing ones to adapt it to the needs. The obtained results of the simulations are positive, i.e., the ideas about the performance of transport protocols over hybrid networks have been validated.

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