INTERACTIONS BETWEEN TRANSMISSION POWER AND TCP THROUGHPUT FAIRNESS IN WIRELESS CDMA NETWORKS[1]

LAURA GALLUCCIO, ALESSANDRO LEONARDI, GIACOMO MORABITO

Dipartimento di Ingegneria Informatica e delle Telecomunicazioni
University of Catania
V.le A. Doria, 6 - Catania 95125 (Italy)
Email: {laura.galluccio, alessandro.leonardi, giacomo.morabito}@diit.unict.it

Abstract: TCP protocols have scarce performance when transmitting over wireless channels. In fact, wireless medium is characterized by multipath fading and high time variability which lead to a great amount of losses in the transmitted packets. In such environments many new problems arise, the most serious of which are the decrease of throughput performance and the unfairness due to the great difference in the Round Trip Times (RTTs) of the connections sharing the same wireless link. In particular, the unfairness is related to the fact that the lower is the RTT of a connection, the higher is its throughput.
In literature many solutions aimed at improving TCP fairness through modifications of the *congestion avoidance* algorithm have been proposed. However, all these solutions are not suitable for wireless networks because they still interpret transmission losses as congestion clue while it is not. In this paper it is demonstrated that the unfairness problem can be solved through appropriate power management. In particular, by letting connections with longer RTT transmit with stronger power, the proposed approach tries to increase the fairness. The performance evaluation is carried out using the NS2 Simulator and interesting simulation results are provided. In particular, it can be observed that, if compared to standard wireless CDMA solutions for transmission over wireless networks, the proposed approach allows to guarantee a good level of throughput and a higher fairness.

keywords: Analytical and Numerical Simulation, Information Networks, Communication Systems.

1 INTRODUCTION

The use of a TCP protocol over wireless networks introduces problems mainly related to the medium characteristics. In fact, it is known that the TCP protocol, thought to work on traditional wired networks, assumes that all losses and possible delays are due to network congestion. When dealing with wireless links, however, packet losses are mainly due to transmission errors. As a consequence, when a timeout elapses, the TCP protocol decreases immediately its transmission rate thus trying to solve congestion. The sudden reduction in the transmission rate, causes a serious decrease in throughput performance as we can see in [Zorzi et al, 2002]. Another problem is the unfairness in the bandwidth allocation when many connections with different RTT share the same congestioned network. This behavior is due to the congestion avoidance algorithm commonly used by the TCP protocol. During the *Congestion Avoidance*, the congestion window is increased by one segment when no congestion is detected, and decreased to half its value when congestion is observed. This mechanism is known as *Additive Increase and Multiplicative Decrease* (AIMD). It is clear that, since the decreasing rate in TCP is about one half for all connections, and the increasing rate is about one segment per RTT, the increase in the transmission rate is not uniform but varies strictly depending on the RTT of each connection [Lakshman and Madhow, 1997]. If TCP works over a wireless network, AIMD is more frequent because of the common link failures which, as said above, are misinterpreted by TCP and considered as congestion clue. If connections with different RTT share the same link, unfairness will be encountered because connections with lower RTT will monopolize resources before slower connections get some bandwidth. In literature, many solutions which aim at improving TCP fairness in various environments have been proposed so far [Henderson et al, 1998; Pilosof et al, 2003]. However, they are mainly based on modifications of the congestion avoidance algorithm and, for this reason, they are suitable only for wired networks. The target of this paper is, instead, to demonstrate that an appropriate power management can give a good improvement in TCP fairness without

[1]This paper was partially supported by CEC under contract ANWIRE-IST 2001-38835

Proceedings 17th European Simulation Multiconference
(c) SCS Europe BVBA, 2003 ISBN 3-936150-25-7

requiring any modification to the congestion avoidance algorithm. Based on this approach, the paper will be organized on follows. In Section Analytical Framework, the analytical framework required for evaluating the transmission power levels needed to obtain the desired fairness is introduced. In Section Performance Evaluation the performance of the considered system is evaluated through simulation. Finally, some concluding remarks are drawn in Section Conclusions.

2 ANALYTICAL FRAMEWORK

The target of this section is deriving an analytical relationship linking the loss probability to the power received by a Base Station and related to a given connection. Our study refers to a system composed of M wireless connections in a W-CDMA scenario. Connections employ a TCP protocol and are characterized by different $RTTs$. Let us say C_i the received power at the Base Station for the i-th connection and let us neglect the thermal noise, because of its lower value with respect to the interference due to the other $M-1$ mobile users [Wu, 1999; Grandhi et al, 1994; Lee and Lin 1996]. Let us consider the $\frac{E_b}{I_0}$ ratio, which is defined as the ratio between the average energy for an information bit, (E_b), and the power spectral density of interference (I_0). The considered ratio, for the i-th user, evaluated at the Base Station, can be written as follows:

$$\left(\frac{E_b}{I_o}\right)_i = \frac{C_i/R_i}{\left(\sum_{j=1\, j\neq i}^{M} C_j\right)/W} = \frac{W}{R_i}\cdot\frac{C_i}{\sum_{j=1\, j\neq i}^{M} C_j} \tag{1}$$

where R_i is the considered user bit rate, while W represents the chip rate chosen equal to that of a FDD-type W-CDMA interface, which is, for UMTS, equal to 3.84 Mcps [Ojampera and Prasad, 1998]. The ratio W/R_i in Eq. (1) represents the so called Process Gain (P_G) of the W-CDMA system. Looking at Eq. (1) it can be observed that, in a W-CDMA multiple access scenario, if the transmission power and thus the received power of a connection increases, an higher $\frac{E_b}{I_0}$ ratio for the same connection is expected. This means that other connections employing the same link will suffer of higher levels of interference. We maintain, in particular, that a right choice of the transmission power distribution for all connections can give an improvement in the overall fairness. To this aim, let us consider the relationship between the Bit Error Rate (*BER*) and the $\frac{E_b}{I_0}$ ratio for the i-th connection. Let us suppose to refer to a spread spectrum system employing a BPSK modulation that is the most common type of modulation employed in CDMA systems. In addition, in order to improve the link reliability observed by TCP, forward error correction (FEC) should be introduced. FEC is based on adding a certain amount of redundancy to the data being transmitted. This redundancy will be used at the destination to correct possible transmission errors which could be encountered. If we consider an information packet of K bits, FEC adds some redundant data, so that the size of the new coded data packet becomes N bits, where $N > K$. According to [Proakis, 1995], the BER for the i-th connection can be written as:

$$BER_i = 12\cdot Q\left(\sqrt{2\left(\frac{E_b}{I_o}\right)_i\cdot R\cdot d_H}\right) \tag{2}$$

In the previous equation, R represents the *code rate* defined as $R = \frac{K}{N}$, d_H is the *Hamming distance* representing the number of bits by which two valid codewords differ from each other, while $Q(x) = \frac{1}{2}\cdot \mathrm{erfc}(\frac{x}{\sqrt{2}})$, where erfc(x) is the *Complementary Error Function*. Since it is known that the relationship between the packet loss probability P_{Loss_i}, and BER_i can be written as:

$${P_{Loss_i}}^2 = 1-(1-BER_i)^{PS} \tag{3}$$

being PS the packet size (in bit), Eq. (3) can be inverted to derive BER_i and thus find a relationship between $\left(\frac{E_b}{I_o}\right)_i$ and $P_{Loss\,i}$.

3 PERFORMANCE EVALUATION

3.1 Simulation Model

In order to solve the unfairness problem and guarantee an equal throughput for all the connections employing the same link, we made a set of simulations to derive the P_{Loss} values which satisfy the condition of giving the same throughput.

In our simulation, we refer to a topology like the one shown in Fig. 1.

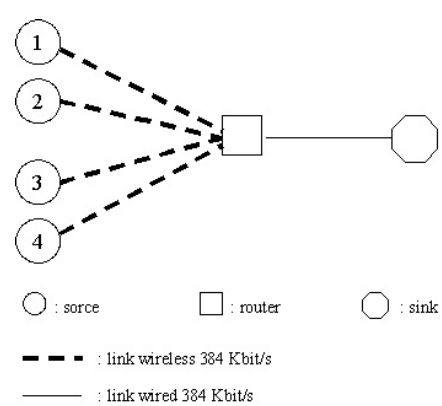

Fig. 1. Network Topology

Four mobile terminals, using a CDMA multiple access interface, communicate with a Base Station through a shared wireless link. This Station is equipped

[2]The formula applies if we assume that bit errors are independently distributed

with a router with an output link connecting to a sink by using a wired link. Connections are grouped in two sets, consisting, each of them, of two connections with the same RTT. The Process Gain value was assumed to be the same for the four connections, i.e. P_G=10, while three different scenarios for the RTT and two set of connections were considered:

- Case I: two of the four connections have the same fixed RTT equal to 100 ms while the other two connections have the same RTT, but variable in the range $[100, 400]$ ms.
- Case II: two of the four connections have the same fixed RTT equal to 200 ms while the other two connections have the same RTT, but variable in the range $[100, 400]$ ms.
- Case III: two of the four connections have the same fixed RTT equal to 300 ms while the other two connections have the same RTT, but variable in the range $[100, 400]$ ms.

Simulations aimed at evaluating TCP performance were done by using the Berkeley Network Simulator [Fall and Vardhan, 1999], version 2. For the characterization of TCP, the New Reno version was used [Floyd and Henderson, 1999], because its implementation of fast recovery and fast retransmit allows to achieve very good performance in wireless networks, if compared to other TCP versions. The TCP connections support a File Transfer Protocol (FTP) application and, in order to model a large file transfer, are represented as always having a packet to send.

In order to simulate a situation of resource sharing, we put a buffer in the router with a FIFO (First In First Out) queue scheme. The maximum queue size was chosen to be 50 packets. In our simulations, data packet size is fixed at 128 byte. The wired link represents the bottleneck of the network and the available bit rate is 384 kbit/s. The packet loss probability P_{Loss} over the wireless links, was assumed to be variable in the range $[10^{-5}, 10^{-2}]$. Simulation parameters are summarized in Table I.

Numerous simulations were run in order to find the values of the P_{Loss} which guarantee the desired fair throughput. The derived values of the packet loss probability were substituted in Eq. (3) so that, combining Eq. (2) and Eq. (1), the searched values for the received power of each connection can be obtained.

3.2 Simulation Results

The performance of the proposed algorithm was evaluated in terms of the average throughput for each of the involved TCP connections as well as of a fairness metric. Our approach was compared with the Standard power controlled technique used in typical cellular and CDMA systems. This Standard scheme aims at limiting the *near-far effect* through an appropriate equalization of the transmission power of all the involved connections.The *near-far effect* is the condition in which, the more a given sender is close to the destination, the higher will be, at this destination, the perceived level of its signal with respect to the other connections. If the Standard scheme is used, the ratio of the received power for the involved connections is one and the $\frac{E_b}{I_0}$ ratio for a particular connection, evaluated at the Base Station, is:

$$\left(\frac{E_b}{I_o}\right)_i = \frac{W}{R_i} \cdot \frac{1}{M-1} \tag{4}$$

If P_G=10 and M = 4, from Eq. (2) and Eq. (3), a P_{Loss} =$8.3 \cdot 10^{-3}$ can be obtained.

As regards the fairness metric, in this paper we refer to a fairness parameter which has demonstrated to be the most complete among those who have been proposed so far in literature. This metric is called the *Jain fairness index* [Jain et al, 1984]. Considering *n* flows, with flow *i* receiving a fraction x_i of the given link bandwidth, the fairness index, using the Jain metric, is defined as:

$$f\left(x_1, x_2, \ldots x_n\right) = \frac{\left(\sum_{i=1}^{n} x_i\right)^2}{n \sum_{i=1}^{n} {x_i}^2} \tag{5}$$

As can be seen in Eq. (5), the fairness index ranges in the interval $[\frac{1}{n}, 1]$.

Figs. 2-7 show the average throughput and the fairness index values for the three considered and above described scenarios. In particular, these figures aim at comparing the performance which can be achieved by using the Standard and Modified power management approaches.

Fig. 2 shows the throughput for the two considered set of connections employing a Modified approach, with respect to the throughput obtained with a Standard equalized approach. In this figure, the couple of connections having the same RTT (i. e. 100 ms) and thus the same throughput, are plot together. As it can be seen, the Modified approach guarantees that the two throughput curves remain very close to each other in spite of the RTT increase. This is the evidence that the fairness we expected can be achieved. On the other hand, a Standard solution causes an increasing difference in the throughput of the two set of connections as long as the RTT increases. In addition, it can be observed that, within 200 ms, the total average throughput, which can be obtained by summing the two throughput contributions for each of the proposed approaches, is the same. Fig. 3 shows the fairness index for the two Modified and Standard approaches. It is evident that, as expected by observing Fig. 2, the fairness which the proposed Modified solution allows to achieve, is very close to 1. This is the evidence that, our power management solution gives, not only an average throughput which is very close to the one which can be obtained in Standard CDMA systems, but also the desirable fairness which, on the other hand, Standard CDMA systems do not preserve, as evident

Parameter	Value
Number of connections	4
TCP version	New Reno
Packet size	128 bytes
Buffer type	FIFO
Buffer size	50 pkts
Wireless link bandwidth	384 Kb/s
P_{Loss}	$10^{-5} \div 10^{-2}$
Wired link bandwidth	384 Kb/s
Simulation time	200 sec

TABLE I
SIMULATION PARAMETERS

in Fig. 3. When the fixed RTT of two of the four connections is 200 ms or 300 ms, Figs. 4-7 can be derived. In these last cases, the situation is additionally improved. In fact, not only the throughput curves derived for the two power management approaches are very close, but also the fairness index obtained with the Modified technique greatly outperforms the one derived for Standard CDMA solutions.

By simulations, it has been observed that, employing a fair throughput strategy actually increases the performance of the system leading to a balance in terms of throughput and reduction of interference for connections sharing the same resources. Finally, it is worth noting that, the Modified approach outperforms, in terms of fairness, the Standard CDMA approach for all the considered scenarios.

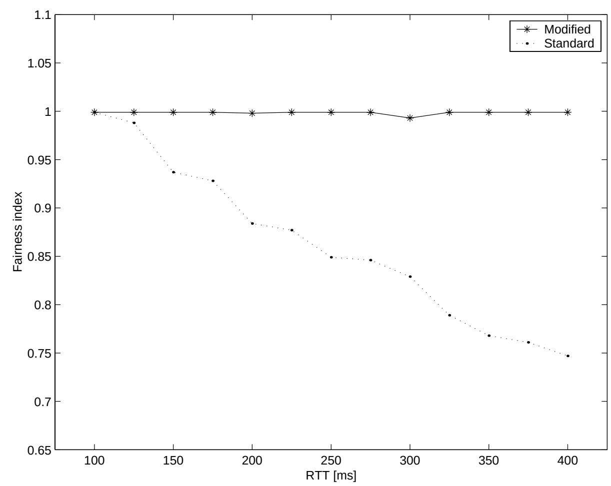

Fig. 3. Fairness index comparison for Modified and Standard approach in Case I.

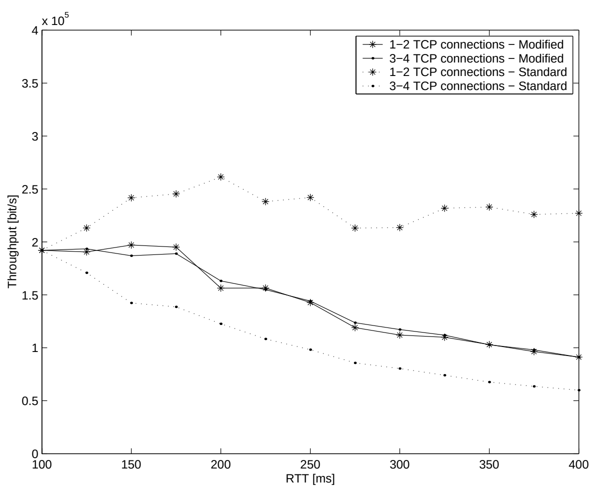

Fig. 2. Throughput comparison for Modified and Standard approach in Case I.

4 CONCLUSIONS

In this paper we have developed a new approach for power management in order to resolve the unfairness problem which arises when many connections with different values of the RTT share the same resources. In particular, by simulations, it has been possible to calculate the required values of transmission power for the involved connections which guarantee the fairness in the exploitation of the available resources. The performance of the proposed power management strategy has been evaluated through simulation and it has been demonstrated that, with respect to a Standard CDMA approach, the introduced approach allows to achieve the desirable fairness as well as a good throughput.

REFERENCES

Zorzi M. Rossi M. Mazzini G. 2002, ”Throughput and energy performance of TCP on a wideband CDMA air interface”, *Journal of Wireless Communications and Mobile Computing (WCMC)*, vol. 2, no. 1, pp. 71-84.

Lakshman T. V. and Madhow U. 1997, ”The performance of TCP/IP for networks with high bandwidth-delay products and random loss”, *IEEE/ACM Transactions on Networking*. vol. 5 no. 3, pp. 336-350.

Henderson T. R. Sahouria E. McCanne S. and Katz R. H. 1998, ”On improving the fairness of TCP congestion avoidance”, *In Proc. of* IEEE GLOBECOM ’98.

Pilosof S. Ramjee R. Raz D. Shavitt Y. and Sinha P. 2003, ”Understanding TCP fairness over wireless LAN”, *In Proc. of* IEEE INFOCOM 2003.

Wu Q. 1999, ”Performance of optimum transmitter

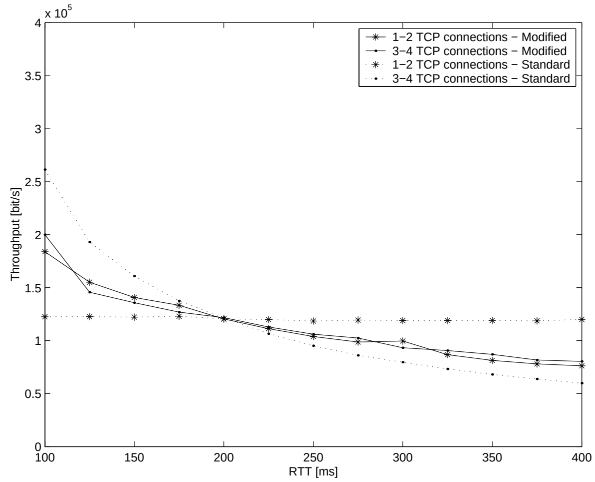

Fig. 4. Throughput comparison for Modified and Standard approach in Case II.

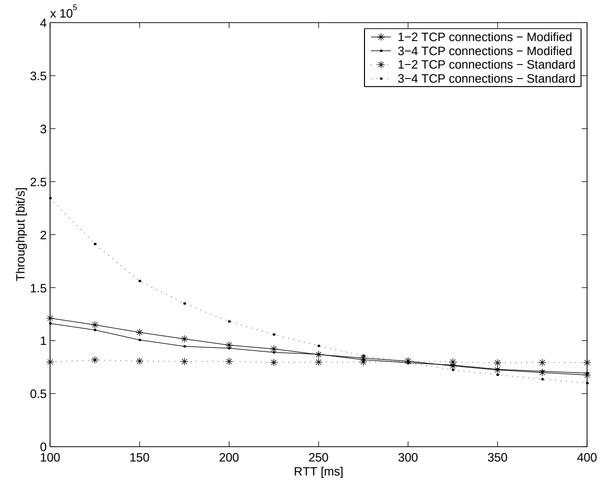

Fig. 6. Throughput comparison for Modified and Standard approach in Case III.

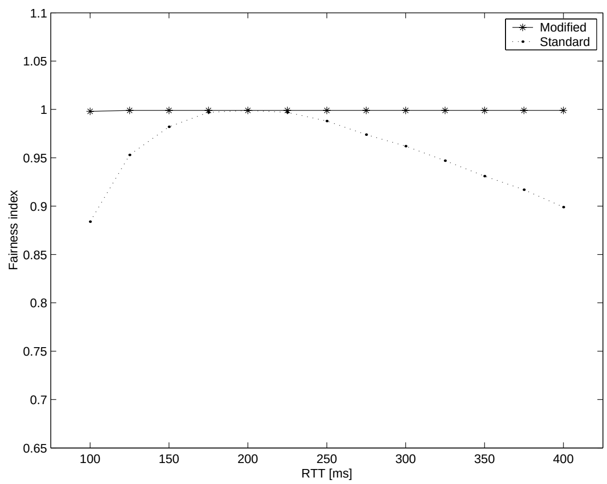

Fig. 5. Fairness index comparison for Modified and Standard approach in Case II.

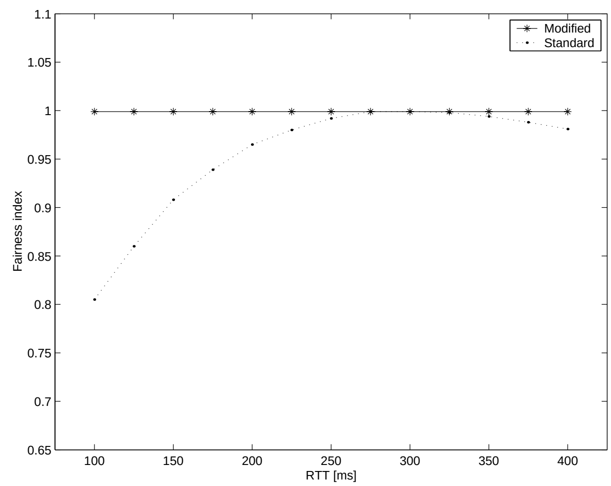

Fig. 7. Fairness index comparison for Modified and Standard approach in Case III.

power control in CDMA cellular mobile systems", *IEEE Transactions on vehicular technology*,vol. 48, no. 2, pp. 571-575.

Grandhi S. A. Vijayan R. and Goodman D. J. 1994, "Distributed power control in cellular radio systems", *IEEE Transactions on Communications*, vol. 42, no. 2-3-4, pp.226-228.

Lee T. H. and Lin J. C. 1996, "A fully distributed power control algorithm for cellular mobile systems", *JSAC*, vol. 14, no. 4, pp.692-697.

Ojampera T. and Prasad R. 1998, "An overview of air interface multiple access for IMT-2000/UMTS", *IEEE Communication Magazine*, vol. 36, no. 9, pp. 82-95.

Proakis J. G. 1995, "Digital communication", Mc Graw-Hill, 3rd Edition.

Fall K. and Vardhan K. 1999, "NS note and documentation", the source code available at http://www.mash.cs.berkeley.edu/ns/.

Floyd S. and Henderson T. 1999, "The NewReno modification to TCP's Fast Recovery Algorithm", Tech. Rep., RFC 2582.

Jain R. Chiu D. and Hawe W. 1984, "A quantitative measure of fairness and discrimination for resource allocation in shared computer systems", DEC Research Report TR-301.

Laura Galluccio received her laurea degree in Electrical Engineering from University of Catania, Catania, Italy in 2001. She is Ph.D student with the Dipartimento di Ingegneria Informatica e delle Telecomunicazioni, University of Catania and also she currently is a CNIT Researcher in the VICOM project. In 2002 she won the International Prize Marisa Bellisario. Her research interests include Satellite and Wireless Networks, Ad Hoc Networks and Network Performance Analysis.