BEHAVIOR OF TCP WESTWOOD IN WIRELESS NETWORKS

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ABSTRACT

Recently we can observe a significant growth in wireless network domain: cellular, cordless, access, point-to-point links and wireless local area network. It is now obvious that future 3G systems should interact with themselves and integrate well with IP-based Internet. Along with development of wireless networks it is also essential to develop protocol layers, especially transport protocols as Transmission Control Protocol. TCP Westwood version seems to have undeniable advantages over other versions. The purpose of this work was simulation research on TCP performance in wireless networks. The results of research show that there are some problems with Westwood version of TCP protocol when applied to heterogeneous networks. These problems are mentioned in this paper. Simulation model based on oTCL language were implemented for ns network simulator.

1 INTRODUCTION

Transmission Control Protocol [7] has been developed for over twenty years for wired networks. Along with development of wireless networks TCP should assure a good performance in heterogeneous infrastructures, which have different characteristics than typical wired networks e.g. random transmission errors in wireless channel. It is worth pointing out that every protocol is developed under certain assumptions. For TCP it was reliable transmission, bi-directional connections, stability, flow control and optional security. Good realization of these features turned TCP/IP protocols stack into foundation of modern Internet. Growing demand for network access caused also network layer evolution – IP protocol which lived version IPv6 at present.
Applications of TCP protocol include File Transfer Protocol, Telnet/Secure Shell, electronic mail SMTP and POP, World Wide Web, peer-to-peer services, chatting, computer games and many more. It is now undisputed that broadband communications is vital for future third generation (3G) cellular systems. Since majority of popular services are related to Internet the 3G systems should integrate well with existing IP-networks. However, IP networks are heterogeneous to a large extent. A good example is infrastructure WLAN combining both wireless and wired environment. WLANs use among other efficient standard IEEE 802.11. Extensions to 802.11 allow to achieve transmission speed of 11 Mbps (IEEE 802.11b) and should enable 54 Mbps in the near future (IEEE 802.11g). Another example may be Wireless Application Protocol (WAP) architecture where the typical TCP connection must be split in gateway between Internet and cellular network. Such heterogeneity may generally lead to bad behavior of TCP.
The most important problem for developers of TCP in wireless networks is high Bit Error Rate. In typical copper cable BER is usually between 10^{-6} and 10^{-7} while in optical fiber between 10^{-12} and 10^{-14}. In wireless channel BER can be as high as 10^{-1}. If in wired network the assumption that lack of acknowledgement meant network congestion, now loss of data may be caused by transmission error. Because TCP uses positive acknowledgements it can not distinguish between these two events and in fact activate algorithms which reduce outgoing data stream. This reaction is unwanted because it results in throughput loss. Other problems with TCP in wireless networks are mobility of network terminals as

notebooks or Personal Digital Assistants, energy consumption reducing amount of additional data available for protocol and network capacity which in wireless domain is much lower than in Ethernet for example.

Several attempts to adjust TCP to new challenges were made although they all are still under development. TCP Westwood proposed in [5] with its bandwidth estimation achieves very good results in wired environment but author of this paper have found some problems with application of TCP Westwood in wireless domain. These problems are briefly discussed in section 3 of this paper.

2 SCRIPTS AND SIMULATIONS

In research the *ns* simulator [3, 4, 6] was applied. *Ns* offers good implementation of TCP and quite good efficiency under Linux operating system. Existing TCP Westwood and TCP Westwood New Reno modules [8] were used.

For the needs of work dedicated scripts were developed. These scripts include results processing algorithm, simulation scenarios and automation of simulation process.

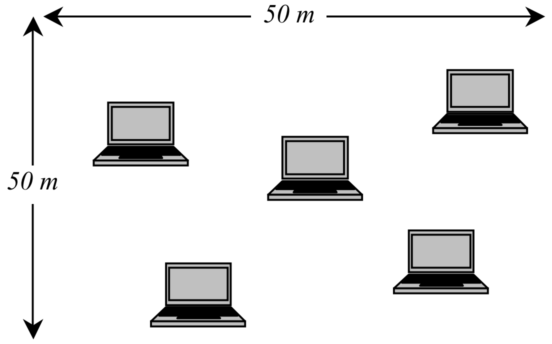

Figure 1. Small ad-hoc network.

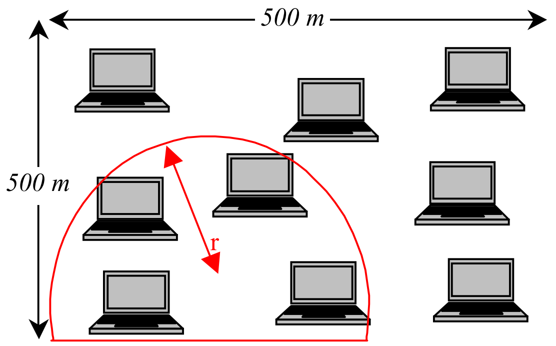

Figure 2. Large ad-hoc network.

Simulations were conducted using *Two Ray Ground* propagation model [3]. The considered network was WLAN using IEEE 802.11 standard [1]. Maximum transmission speed for this standard is 2 Mbps. There was rate-based error model assumed. Three topologies used was small and large ad-hoc networks (Fig. 1 and Fig. 2) and infrastructure network (Fig. 3).

For high area dimensions range of mobile station is limited. In scenarios the range assumed was $r = 250$ *m* (Fig. 2).

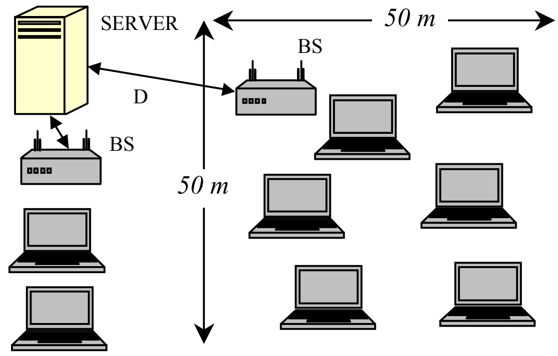

Figure 3. Infrastructure network.

The most common topology today is infrastructure network. The area is often small and traffic is mostly directed to wired network through Base Stations rather than other mobile stations. Link propagation delay *D* is variable set as simulation parameter.

In the next section we will concentrate on one of the most promising TCP version – TCP Westwood and its bandwidth estimation algorithm.

3 TCP WESTWOOD

The end-to-end nature of TCP protocol makes the need for implementing congestion control mechanisms either in sender or receiver TCP agent. TCP Westwood introduces changes in sender node only. According to this, it is not required to replace all existing software as in other versions e.g. SACK and new Westwood-based nodes can easily join the network compatible even with RFC 793.

The mechanisms implemented in sender node use ACK acknowledgements to calculate bandwidth available to sender and limit amount of outgoing data. This technique gives a lot of opportunities to increase TCP efficiency and was also used in latest Vegas and Westwood versions.

One of vital features in TCP Westwood is bandwidth estimation algorithm which runs in sender TCP agent. TCP Westwood combines averaging rate of returning ACK with distinction between different events when cumulative and delayed acknowledgements arrive. The rate of returning ACK is based on time intervals between consecutive ACK arrivals. This rate is then used to calculate temporary bandwidth samples. Since this samples change very dynamically it is required to average their rate. Averaging is done by using discrete time filter which is obtained by discretizing a continuous low-pass filter using Tustin approximation.

The value of available bandwidth is calculated [5] according to equation:

$$\hat{b}_k = \frac{\frac{2\tau}{\Delta t} - 1}{\frac{2\tau}{\Delta t} + 1} \cdot \hat{b}_{k-1} + \frac{b_k + b_{k-1}}{\frac{2\tau}{\Delta t} + 1} \qquad (1)$$

where:

$\hat{b}_k, \hat{b}_{k-1}$ [bps] are filtered measurement of the available bandwidth as acknowledgements number k and (k-1) arrive,

b_k, b_{k-1} [bps] are proper samples of bandwidth,

$1/\tau$ [1/s] is the cut-off frequency of the filter,

$\Delta t = t_k - t_{k-1}$ [s] is the time interval between consecutive acknowledgement arrivals.

Estimation algorithm also respects different events which occur when acknowledgements arrive. The most important is distinction when ACK is cumulative and delayed because the same ACK should not be counted twice or more. At the end the value of estimated bandwidth is used to calculate parameters for typical TCP congestion avoidance mechanisms as congestion window and slow start threshold after a congestion episode.

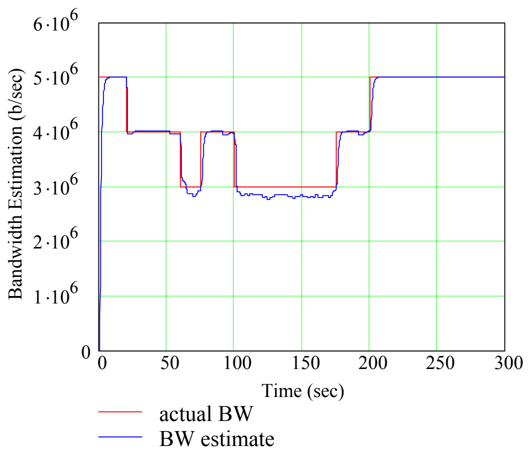

Figure 4. Effectiveness of bandwidth estimation for wired 5 Mbps link with TCP Westwood.

Bandwidth estimation in TCP Westwood is accurate although shows tendency to under-estimation. It can be observed on figure 4 that estimation is close to real bandwidth. It should be slightly higher because TCP must keep a certain excess of data in network to receive return information about network capacity. We could expect that effectiveness of estimation given by TCP Westwood is at least comparably good in wireless network.

4 TCP WESTWOOD IN WIRELESS

In this work there were simulation research conducted. The results of these research show that TCP Westwood does not find application in wireless networks at present. The unexpected problems appear during transmission and they are described in this section.

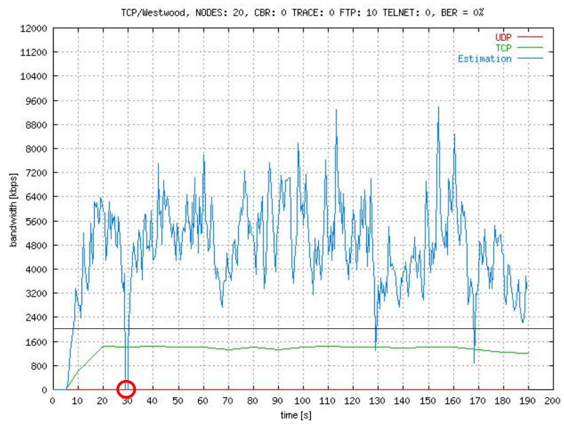

Figure 5. Negative bandwidth estimation in TCP Westwood.

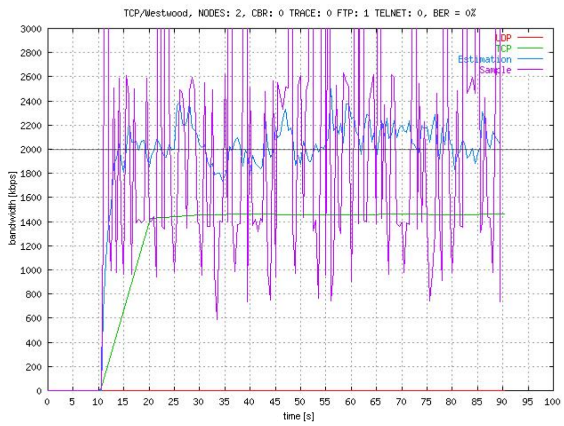

Figure 6. Wrong bandwidth sampling in TCP Westwood in the simplest ad-hoc network.

Figure 5 presents real bandwidth achieved in ad-hoc network (green) and total TCP Westwood bandwidth estimation (blue). To make the graph legible there were marked values every 5 seconds. In fact the estimation is calculated every acknowledgment. The black line indicates maximum available network bandwidth of 2 Mbps. The scenario assumed 10 FTP sources in 20 nodes network. The error rate BER was set to 0 %. After 29 seconds of work the total estimated bandwidth (10 sources) fell down below zero. This leads to stop TCP agent and whole simulation. The rest of graph was obtained by modifications of sources.

Another problem is wrong value of estimated bandwidth. Figure 6 shows simplest ad-hoc network with only two nodes and one FTP source. The Bit Error Rate in wireless channel was set to 0% and losing packets due to channel errors was not taken into consideration. As it can be noticed samples of bandwidth (purple) are enormous high which results in higher estimated bandwidth (blue) than could be expected. To make matters worse, calculated estimation is even higher than physical network capacity.

The reason for this is as follows. When TCP receiver delays acknowledgements it usually acknowledges 2 TCP segments ($2 \cdot 1000 \cdot 8 = 16000$ bits) [9]. In wireless domain signal propagation time is very low. For small ad-hoc network it can be as low as 100 ns [2]. Thus, intervals between consecutive acknowledgements may be also very low. If interval is as low as 1 ms the sample gives 16 Mbps which is obviously wrong (out of scale samples on figure 6). To achieve correct sample in this way the interval should be about 12 ms in 2 Mbps network assuming 75 % TCP efficiency. Although average interval in scenario was 14 ms, more than half of all was below 12 ms. In result we have overestimated bandwidth during whole simulation. The following example shows the need for eliminating wrong bandwidth samples in order to obtain correct estimation value.

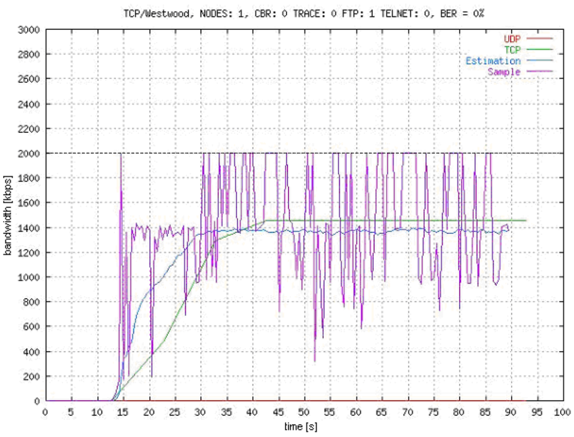

Figure 7. Improved bandwidth estimation in infrastructure network.

The bandwidth estimation can be easily improved by simple limitation of wrong samples (Fig. 7). As an example simple one-node infrastructure network with one FTP source was presented. Wrong bandwidth samples was limited to 2 Mbps which determines the capacity of examined network. Although that limitation is not a global solution because the exact maximum network capacity is unknown, we can achieve effectiveness almost comparable to wired link (Fig. 4). For accurate estimation the adequate algorithm should not rely on ACK intervals only.

The reason for reaching zero estimation is different. In heavily congested WLAN wireless network acknowledgements can arrive with out-of-order sequence. In the worst case observed during simulations some out-of-order cumulative acknowledgements are calculated as negative. Because of this the bandwidth samples are also negative. When Δt time is low enough the equation (1) leads directly to calculation

$$\hat{b}_k < 0 \tag{2}$$

which make sender TCP agent impossible to continue its work.

Although described problems were observed in ad-hoc wireless network they can still appear in infrastructure topology or even in other heterogeneous wired network.

5 CONCLUSIONS

The problems in TCP Westwood bandwidth estimation algorithm were revealed in this work. This algorithm should be reconsidered with mixed combination of delayed and cumulative acknowledgements. Bandwidth estimation should be very accurate and fast in order to allow the sender to respond to changing traffic in network. Discrete time filtering used in TCP Westwood meets this demand, but we can expect that estimation must take into consideration not only intervals between consecutive acknowledgements but also time of sending TCP segment (in fact round trip time).

Authors contacted with TCP Westwood developers and the next version of bandwidth estimation algorithm and ns-2 modules are going to be available soon.

It is worth pointing out that new solutions must be tested in complex topologies with heavily congested network as it was conducted in this work or similarly. This is primary assumption which assures that new protocol will work correctly in real network characterized by very dynamic parameters.

6 FUTURE WORK

Implemented scripts may be used for further research on TCP protocol and its detailed performance evaluation. Many detailed scenarios are still being beyond recognition. It would be very interesting to study faster networks e.g. 802.11b WLAN as well.

REFERENCES

[1] ANSI/IEEE 802.11 Standard, 1999 Edition. “Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications”. http://standards.ieee.org

[2] B. Bing. “High-Speed Wireless ATM and LANs”, Artech House, 2000.

[3] K. Fall, K. Varadhan. “The ns manual”. VINT Project. UC-Berkeley, LBL, USC/ISI, Xerox PARC16, February 2002. http://www.isi.edu/nsnam

[4] S. McCanne, S. Floyd. Ns simulator version 2.1b8a, August 2000. http://www.isi.edu/nsnam

[5] S. Mascolo, C. Casetti, M. Gerla, M. Y. Sanadidi, R. Wang. “TCP Westwood: Bandwidth Estimation for Enhanced Transport over Wireless Links”. ACM SIGMOBILE 2001 Rome, Italy.

[6] CMU Monarch Project. “Wireless and Mobility Extensions to ns”, August 1999. http://www.monarch.cs.rice.edu

[7] RFC 793. “Transmission Control Protocol. DARPA Internet Program. Protocol Specification”, September 1981.

[8] TCP Westwood ns-2 modules, January 2002. http://www.cs.ucla.edu/NRL/hpi/tcpw

[9] G. R. Wright, W. R. Stevens. “TCP/IP Illustrated”. Addison-Wesley 1995.