Информационные процессы, Том 2, № 2, 2002, стр. 270–272.

KALASHNIKOV MEMORIAL SEMINAR

Estimation of Maximal TCP/IP Traffic Rate over 802.11 Network with Hidden Stations[1]

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Received October 14, 2002

IEEE 802.11 [6] is one of the most popular protocols for wireless networking. In contrary to western countries where this protocol is exploited in local area networks (LANs) and campus networks, in Russian Federation the 802.11 infrastructure networks are used as distribution systems for integrated LANs. An example of this sort of networks is Moscow wireless network Radionet (see [5]) developed to integrate LANs of Moscow research institutes, universities and colleges and to provide their users an access to Internet.

A typical cell of this network is star-form and consists of a basic station (an access point to an external network) and N end stations being the portals for LANs. All of end stations are hidden from each other, and their aerials are focused on the basic station so that all information exchanges occur only through the basic station.

In previous works [1, 2, 3], and [4], 802.11 network performance has been studied analytically in the saturation conditions when there are always queues for transmitting at every network station. In the considered network, downlink traffic (that is from the basic station to end stations) prevails, because the most of users' requests are related to external network information resources, and the main fraction of the traffic is related to large file transmissions (FTP-like traffic). Therefore, the saturation condition can take place only at the basic station, while uplink traffic consists mainly of short TCP/IP acknowledgments on TCP/IP packets which end stations receive from the basic station.

More exactly, to estimate the maximal traffic provided for TCP/IP connections by the 802.11 network, we assume the following:

- There are a lot of TCP/IP connections between users of LANs integrated to the considered network and the external world, and an infinitely long file is transferred from the external world through every connection, i.e., these connections are stable for a long time.
- TCP/IP connections are distributed uniformly over all end stations.
- Bit error rate is constant and the same for all stations.
- Time intervals when TCP/IP packets are transferred and processed outside the 802.11 network are negligible.

In particular, these assumptions mean that, firstly, a freed place in the basic station's buffer is occupied immediately by the next TCP/IP packet, which destination is at any of integrated LANs with equal probability; secondly, a TCP/IP acknowledgment is placed in the end station's queue immediately upon a TCP/IP packet receipt.

[1] This work was partially supported by NATO Science Programme in the Collaborative Linkage Grant PST.CLG.977405 "Wireless Access to Internet exploiting the IEEE 802.11 technology".

To study the 802.11 network, we subdivide the time of its operation into non-uniform virtual slots (from the basic station's point of view), each of them being either (a) an "empty" slot in which no station transmits; or (b) a "basic success" slot (BS-slot) in which the basic station transmits successfully; or (c) an "end success" slot (ES-slot) in which one and only one end station transmits and this transmission is successful; or (d) a "failure" slot in which either a collision takes place or any of transmitted frames is distorted by noise.

Let us describe a network state by the number ℓ of TCP/IP acknowledgments waiting for their transmission and assume all variants of acknowledgments allocation over end stations are equiprobable. Then the network behaviour can be described by the birth-and-death process with discrete time which unit is a virtual slot, where birth (λ) and death (μ) probabilities are:

$$\lambda(0) = p_{bs}(0), \quad \lambda(\ell) = \sum_{n=1}^{\min(N,\ell)} p_{bs}(n)\gamma(n,\ell), \quad \mu(\ell) = \sum_{n=1}^{\min(N,\ell)} p_{es}(n)\gamma(n,\ell),$$

where $p_{bs}(n)$ and $p_{es}(n)$ are probabilities of BS- and ES-slots taken under condition that there are n active end stations (which queues are not empty), while $\gamma(n,\ell) = \binom{N}{n}\binom{\ell-1}{n-1} / \binom{N-1+\ell}{\ell}$ is the probability that there are n active end stations with ℓ waiting TCP/IP acknowledgments. Assuming the common limit L for all end station queue sizes, we obtain the steady-state probabilities $\pi(l)$ for this birth-and-death process states.

Excluding TCP/IP packet duplicates occurring because of TCP/IP acknowledgment losses, we find the sought throughput, that is, the average TCP/IP payload transferred per a second from the external world to the network users:

$$S \;=\; P\left\{\sum_{\ell=1}^{L}\mu(\ell)\pi(\ell)\right\} / \left\{t_{slot}(0)\pi(0) + \sum_{\ell=1}^{L}\pi(\ell)\sum_{n=1}^{\min(N,\ell)} t_{slot}(n)\gamma(n,\ell)\right\},$$

where P is a payload contained in a TCP/IP packet, while $t_{slot}(n)$ is the average duration of a virtual slot in the condition of n active stations.

Values of $p_{bs}(n)$, $p_{es}(n)$, and $t_{slot}(n)$ are obtained by studying the similar network $\mathcal{U}_n$ consisting of the basic station and n end stations, each of them working in saturation. To analyze the network $\mathcal{U}_n$, we develop our method [3] to take into account of the difference between collisions of hidden and exposed stations: a frame transmitted by station A is distorted due to the collision which happens because of station B concurrent transmission when both stations start transmitting at the same instance, in case of exposed stations, or when one of these stations starts transmitting at any instance during the other station transmission, in case of hidden stations.

Numerical results of our analytical study show that collisions of TCP/IP acknowledgments can waste severely the network throughput even with a few stations. As a result of these collisions, the uplink throughput measured in packets transmitted per a second appears to be less significantly than the downlink throughput, which leads to frequent TCP/IP acknowledgment losses. Simulation of the considered network approve this conclusion and show high accuracy of our method.

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