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Performance of Communication Protocols Using Multiplexed Channels

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Abstract. The protocol efficiency is the most usually used protocol performance measure; it defines the maximum throughput in a nonmultiplexed environment and determines the quality of a protocol from the user's viewpoint. In this paper, the protocol relative efficiency is defined as the ratio of a successful transfer rate against the load imposed on the channel resources and indicates the performance of a protocol in a multiplexed environment from the system's viewpoint. It is shown both analytically (under some reasonable assumptions) and with simulations that it indicates the system efficiency in a multiplexed environment, although it can be evaluated in a nonmultiplexed environment. The results of the performance analysis were confirmed with simulation results. Simulation of the sliding window protocols also showed the relative efficiency to be a relevant performance measure for the protocols running in a multiplexed environment and to yield different results than the conventional protocol efficiency. It is also shown that, although the stop-and-wait protocol is always considered to be the least efficient among the sliding window protocols, this is true only in nonmultiplexed environments, while in multiplexed environments the go-back-N is the least efficient and the stop-and-wait is equally efficient as the selective-repeat protocol.

Keywords: communication protocol, protocol efficiency, relative protocol efficiency, system efficiency

Učinkovitost telekomunikacijskih protokolov v multipleksnih okoljih

Učinkovitost protokola je mera, ki jo najpogosteje uporabljamo za ocenjevanje prometnih lastnosti protokola s stališča uporabnika v kanalih, kjer ne uporabljamo multipleksiranja; definirana je kot največji mogoči prometni pretok, ki ga protokol dopušča v kanalu. V tem članku je definirana relativna učinkovitost protokola kot razmerje opravljenega prometnega pretoka proti pretoku, s katerim protokol obremenjuje vire kanala. Relativna učinkovitost predstavlja mero za kakovost protokola v multipleksnem okolju s stališča sistema. V članku pokažemo analitično in s simulacijami, da relativna učinkovitost opisuje učinkovitost sistema v multipleksnem okolju, četudi jo lahko ovrednotimo v okolju, ki ne uporablja multipleksiranja. Rezultate analize učinkovitosti smo potrdili s simulacijami. Rezultati simulacij protokolov z drsečim oknom kažejo tudi, da je relativna učinkovitost smiselna mera za ocenjevanje kakovosti protokolov v multipleksnih okoljih, saj analizi učinkovitosti in relativne učinkovitosti dajeta različne rezultate. Čeprav protokol s čakanjem ″slovi″ kot najmanj učinkovit med protokoli z drsečim oknom, smo s simulacijami pokazali, da to drži samo v nemultipleksnih okoljih, medtem ko je v multipleksnih okoljih s stališča sistema enako učinkovit kot protokol s selektivnim ponavljanjem, najmanj učinkovit v takih okoljih pa je protokol s ponavljanjem zaporedja.

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1 INTRODUCTION

One of the most important properties of a communication protocol is its performance which indicates the quality of a protocol concerning the utilisation of available resources from the user's or from the system's point of view. The performance measures that are usually used often take only one of the two viewpoints into account.

Two different cases must be distinguished. In the nonmultiplexed case, the resources of a channel are used by a single communication process; they must therefore be successfully used as much as possible so that the protocol provides the best possible service for the users of the communication system. On the other hand, in the multiplexed case, the resources are shared among several communication processes; hence, it is of utmost importance that a communication process utilises as few resources as possible to provide the service with a certain quality, and leaves other resources to be used by other communication processes. In other words, the service that is achievable per channel resources is interesting in the nonmultiplexed case, while the amount of resources used per service is interesting in the multiplexed case. Or, yet in other words, in the nonmultiplexed case, the service outcome must be normalised by the total amount of resources offered by the channel, while in the multiplexed case, the service outcome must be normalised by the amount of resources that are actually used by a communication process.

In this paper, the transmission rate will be the resource of interest. Hence, the degree of utilization of the available channel rate that a process is capable to use for user information transfer is important in the nonmultiplexed case from the user's viewpoint as it determines the maximum throughput that can be achieved. On the other hand, in the multiplexed case, the ratio of the transfer rate provided by the protocol to the users over the load imposed by the protocol on the overall channel rate is more important from the system's viewpoint.

The measure that is most often used to evaluate a protocol performance is the protocol efficiency, or, in other words, the maximum throughput that can be obtained by a protocol in the nonmultiplexed environment [1, 2], and is most important from the users' viewpoint. In this paper, a new measure will be introduced which indicates the performance of a protocol in the multiplexed environment and is most important from the system's point of view.

2 The Nonmultiplexed Channel Case

The protocol performance is usually considered in a nonmultiplexed channel case. The traffic measures in such cases are the input rate $r_g, r_g \leq R$ (where R is the channel nominal rate), with its normalised value $G = r_g/R \leq 1$ usually referred to as the offered load, and the output rate r_s, $r_s \leq r_g$, with its normalised value $S = r_s/R \leq G$ called the throughput (while r_g accounts for all bits that are transmitted into the channel in a time unit, r_s accounts for only those that are useful from the receiving user's point of view). The maximum throughput value that is achievable is called the protocol efficiency η, $\eta = S_{max}$ (sometimes also link utilisation or capacity [1, 2]) and is very often used as the performance measure in nonmultiplexed cases. Hence, the protocol efficiency expresses the throughput a protocol is capable to transfer on a channel, and consequently the maximum transmission rate between the two users.

3 The Multiplexed Channel Case

Let us now consider the case of N subchannels multiplexed onto a multiplexed channel with a nominal rate R. Let the rate r_{gi} be fed into the i-th subchannel, and the rate r_{si} successfully drawn from it. Both rates can be normalized with R to yield the offered load $G_i=r_{gi}/R$ and throughput $S_i=r_{si}/R$, respectively, per channel. The rate generated into the multiplexed channel is then $r_g^M = \sum r_{gi}$, the total successful rate is $r_s^M = \sum r_{si}$, and the total offered load and throughput of the system (multiplexed channel) are $G^M = r_g^M/R = \sum G_i$ and $S^M = r_s^M/R = \sum S_i$, respectively. The efficiency of a single subchannel $\eta_i = (S_i)_{max}$ is not relevant, as a subchannel has only a fraction of the system capacity (rather than the nominal rate R) at its disposal, and this fraction depends on the traffic of other processes using the same multiplexed channel. However, the efficiency of the multiplexed channel $\eta^M = S_{max}^M$ is important from the system's point of view, as it indicates the total throughput that can be carried by the multiplexed channel. Hence, let η^M be referred to as the system efficiency. In order to describe the performance of a protocol in a multiplexed environment, a performance measure is needed that depends solely on the protocol and channel properties and can be related to the system efficiency. Such a measure will be introduced in the next Section.

4 Relative Protocol Efficiency

We will define the relative protocol efficiency in a nonmultiplexed case as

$$\sigma = \frac{r_s}{r_g}. \quad (1)$$

In a similar way, we can define the relative protocol efficiency of the i-th subchannel of a multiplexed channel to be $\sigma_i = r_{si}/r_{gi}$ and the relative efficiency of the multiplexed channel as $\sigma^M = r_s^M / r_g^M$.

The relative efficiency does not depend on the amount of resources available, so it depends only on the protocol and channel properties.

5 Assumptions

In order to be able to find the relation between the nonmultiplexed case relative efficiency σ and the system efficiency η^M in a multiplexed case, the following simplifications will be assumed: (i) the number of subchannels N of the multiplexed channel is large ($N \to \infty$); (ii) all subchannels have the same properties (e. g., loss rate), and the same protocol is used in all of them ($\sigma_i=\sigma_j$); (iii) the load on all subchannels is balanced ($r_{g_i} = r_{g_j}$). Although these assumptions are not always fulfilled in practice, we can use them in order to estimate the performance of a protocol in a multiplexed environment and to compare the performances of different protocols in such environment.

Furthermore, we will assume that the multiplexed channel has the same properties (such as the bit error rate) as the nonmultiplexed channel, and the same protocol is used in both cases. As the relative efficiency depends only on the protocol and channel properties, $\sigma = \sigma_i$ must hold for any i.

Based on the assumption (i), one is tempted also to assume $G^M \to 1$. While all the above assumptions were confirmed to be true with simulation results, $G^M \to 1$ is sometimes true and sometimes not, as it may well happen that none of the protocol entities has the right to transmit at a certain time period, due to the limitations of the protocol.

6 SYSTEM EFFICIENCY

Under the above assumptions, the following facts are valid. From (ii) and (iii) we have $r_g^M = N \cdot r_{gi}$ and $r_s^M = N \cdot r_{si}$, $S^M/G^M = \sigma^M = \sigma_i = \sigma$, and therefore

$$S^M = \sigma \cdot G^M. \quad (2)$$

If $G^M \to 1$ is true, $S^M = \sigma$ is also true; this S^M is the maximum throughput and thus by definition equal to the system efficiency:

$$\eta^M = \sigma. \quad (3)$$

In any case, if the maximum offered load G^M has been achieved, even if it is lower than 1, (2) indicates the system efficiency. Evidently, the system efficiency of a multiplexed channel where a communication protocol is running in all subchannels is determined by the relative efficiency σ of the same protocol running in a nonmultiplexed channel, according to (2) or (3), rather than by the protocol efficiency η. Hence, the relative protocol efficiency σ, as defined in (1), gives the measure for how well a protocol behaves in a multiplexed environment. This is the consequence of the fact that, with statistical multiplexing, the system resources are dynamically assigned to different communication processes; from the system's point of view, it is more important how many system resources a communication process uses (r_{gi}) to implement a service (r_{si}) than which throughput it can get out of the system resources (R).

7 EXAMPLE - SLIDING WINDOW PROTOCOLS

As a typical example, let us now consider the family of the sliding window protocols [2-4] which can be used either in a nonmultiplexed or multiplexed arrangement. The three special cases that are usually used and analysed are stop-and-wait, go-back-N and selective-repeat protocols. The first one has the lowest efficiency, and the efficiency of the other two protocols is much better, the efficiency of the selective repeat protocol being slightly better than the efficiency of the go-back-N protocol.

If the relative efficiency is considered instead, the results look much different. The relative efficiency of the go-back-N protocol is expected to be much inferior (due to the unnecessary retransmissions of the already successfully transferred packets) compared with the relative efficiencies of the other two protocols. The basic automatic-repeat-request mechanisms of stop-and-wait and selective-repeat protocols being essentially the same (the former is a special case of the latter [4]), their relative efficiencies can even be expected to be the same. Hence, the go-back-N protocol is not suitable for a multiplexed environment. On the other hand, stop-and-wait and selective-repeat protocols are suitable; while the former is very simple but inefficient from the user's point of view in a nonmultiplexed environment, the latter behaves well in both multiplexed and nonmultiplexed environments.

8 SIMULATION RESULTS

The sliding window protocols (stop-and-wait, go-back-N and selective-repeat) were simulated with different sets of protocol/channel parameters both in nonmultiplexed and multiplexed (100 equally loaded connections) environments. As proposed in Section 5 (Assumptions), the same protocol with the same protocol/channel parameters was always used in all connections and compared with the results of the same scenario in the nonmultiplexed arrangement. The basic protocol (using only those mechanisms that are necessary for the logical correctnes) was always used. In the multiplexed environment, the timer expiration time had to be set to the value $T_{to} = T_{rt} \cdot N \cdot W_t$ (where T_{rt} is the round-trip time, N the number of multiplexed connections, and W_t the transmit window width), in order to obtain a stable protocol behaviour.

As expected, the assumptions $S_i = S_j$ and $\sigma = \sigma_i = \sigma_j = \sigma^M$ were confirmed for any i and j (with very low standard deviation, due to simulation results dissipation). At low bit error rates, $G^M = 1$ was always true. At high bit error rates, sometimes this condition was still true, but in some cases, G^M dropped below the value of 1. This happened especially in cases of long channel delays and hence large transmit window widths. When $G^M = 1$ was true, (3) was always valid. However, in case of $G^M < 1$, the system efficiency η^M was also lower than the relative efficiency σ according to the relation (2).

Fig. 1 shows a typical example of simulation results for the system efficiency, relative protocol efficiency and offered load of the go-back-N protocol (with nominal bit rate 1 Mb/s, channel delay 1 ms, user message length 100 octets, overhead/acknowledgement 5 octets, and transmit window width 4) in a multiplexed scenario. As long as the offered load remained close to 1, the system efficiency η^M and relative protocol efficiency σ also had almost the same values. At higher bit error rates where the offered load dropped below 1, the system efficiency also dropped below the relative efficiency, according to (2). The relative efficiency had almost the same value (with the difference less than 0.2 % at all bit error rates) as in the nonmultiplexed case. Similar results were obtained with other scenarios.

Fig. 2 shows the protocol efficiency of the three sliding window protocols (the nonmultiplexed case) with the same parameters as in Fig. 1 (with transmit window width 4 in both continuous protocols), and Fig. 3 shows the relative efficiency for the same scenarios. While the protocol efficiency of the selective repeat protocol is the highest and that of the stop-and-wait protocol is the lowest, the relative efficiencies of the stop-and wait and selective-repeat protocols are almost equal and that of the go-back-N protocol is much lower, as expected.

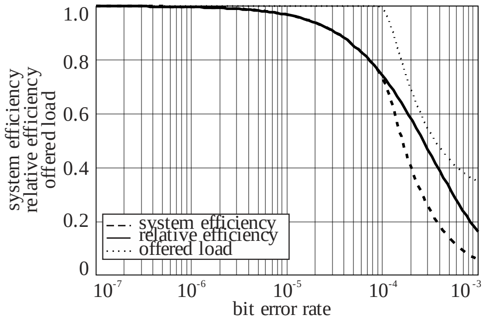

Figure 1. System efficiency, relative protocol efficiency and offered load of the go-back-N protocol in a multiplexed environment.

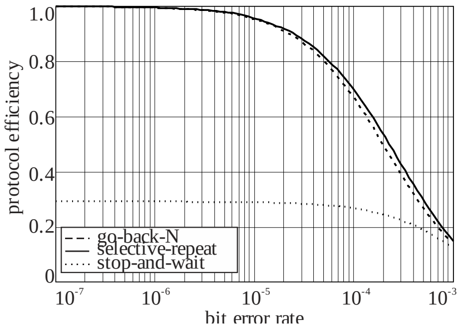

Figure 2. Protocol efficiency of the sliding window protocols.

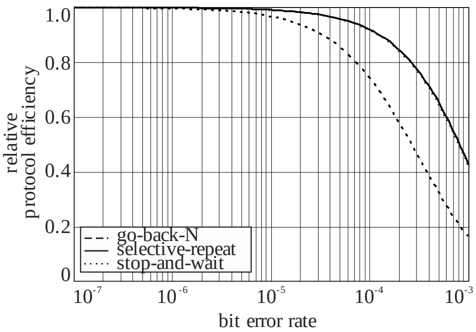

Figure 3. Relative protocol efficiency of the sliding window protocols.

9 CONCLUSION

A new performance measure for communication protocols was proposed which takes into account the resource usage both in nonmultiplexed and multiplexed environments and describes the performance of a protocol from the system's point of view. The relative protocol efficiency determines the system efficiency in a multiplexed environment, but can be simply evaluated in a nonmultiplexed scenario.

While the protocol efficiency can continue to serve as an important measure of the quality of a protocol that is to be mostly used in a nonmultiplexed environment, the relative efficiency is a more appropriate measure to assess the quality of a protocol intended to be used in a multiplexed environment. The quality of a protocol which is expected to be used in mixed environments should be estimated with both the protocol efficiency and the relative protocol efficiency.

The relevance of the new performance measure was demonstrated with simulations of the sliding window protocols. It was shown that, although the stop-and-wait protocol is always considered as the least efficient among the three types of the sliding window protocols, this is true only in nonmultiplexed environments, while in multiplexed environments, the stop-and-wait protocol is equally efficient as the selective-repeat protocol and the go-back-N protocol is the least efficient. However, in mixed environments, the selective-repeat protocol is the best one as it behaves efficiently both in multiplexed and nonmultiplexed environments.

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