A Study towards Enhanced Reliability Performance of Remote Control and Monitoring Application over Commercial Wireless Communication Networks

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Abstract

Remote control and monitoring systems provide many useful operating advantages in industrial automation and demand highly reliable and secure communication means. Their widespread use is, however, limited because of the high cost of current communications in use making them economically infeasible. Hence, there is a need to develop new low cost communication and control concepts by making such solutions economically feasible. In this paper, we present a scheme for implementing reliable wireless communication links for application of remote control and monitoring system based on current available commercial wireless communication networks e.g. GPRS/EDGE/UMTS. The reliability enhancement over wireless networks has been proposed and its performance has been studied. This paper examines the proposed solution by means of both analytical and numerical evaluation, and has shown that the demanded reliability performance can be met by using only commercial wireless communication networks.

Keywords: reliability, performance, quality of service

1. Introduction

This paper is targeting on typical reliability-demanding industrial remote control and monitoring applications. Currently, the high cost of wired or wireless communication in use of telecontrol equipment has had major impact in shaping the network topology, which in turn requires new low cost wireless communication solutions. Present remote control and monitoring systems need to be updated due to new requirements and the usability of present network can be improved by using new ICT solutions.

According to the research of [1], commercial wireless communication networks are now more and more considered for remote control and monitoring applications, even for some reliability-critical applications. By providing related enhancement in reliability, they have shown some distinct and irreplaceable advantages.

This paper studies the performance of the proposed reliability enhancement of remote control and monitoring system in wireless communication networks, by using analytical methods and numerical evaluation. The main objective is to evaluate the performance of obtained QoS, e.g. the overall blocking probability and the average queuing time for this particular system, with hybrid communication means of EDGE/GPRS/GSM. The study shows such system is able to achieve reasonably high reliability in remote access over normal commercial wireless communication networks.

2. Redundant design for enhanced reliability

Since the remote control and monitoring application demands highly reliable wireless data link, this can only be resolved from improving system redundancy design point of view rather than improving network technology point of view, because of the unpredictable nature of commercial wireless communication network. In this case, the idea is that the system with redundancy design will always have multiple possibilities to maintain an operational and accessible status in case of failure of part of its communication means.

The desired wireless remote control and monitoring system normally consists of the following modules: communication module, processing module, control and monitoring module. According to the reliability theory [2], the most critical part of the system should have redundancy design to be duplicated or even triplicated, which is particularly the communication module in our case. The communication module has relatively higher probability to fail, not because of the physical failure of data terminal but because of the network traffic congestion. Since the entire remote control and monitoring system completely relies on wireless communication which failure probability is based on majority of the sophisticated network traffic rather than the reliability of the components, it is the most critical part in the system. Of course each component of the modules has a probability to fail, but the idea is to utilize redundancy design for the modules which are more likely to fail and in

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turn to improve the reliability in order to fulfill the requirements. From the following analytical and numerical evaluation we will prove the proposed redundancy design to be effective which can dramatically improve the system reliability.

3. Background of the performance analysis

The initial method of data transmission in GSM is circuit switching, which reserves the traffic channel for the entire communication time, and wastes the radio resource when data traffic occurs in bursts with long silent intervals. GPRS over the GSM has been specified to increase the utilization efficiency of the radio resource so that the physical channels unused by circuit switched services are allocated dynamically to the GPRS according to the actual needs for packet transfers. In the study here, from network resource allocation point of view a GSM circuit switched data call is assumed to be equivalent to a GSM voice call and therefore the evaluation is done for voice to represent CSD performance.

Based on [3] GPRS is an overlay on GSM networks that allows end-to-end IP-based packet traffic from the terminal to e.g. the Internet. EDGE is an improvement over GPRS whereas the modulation scheme on radio is modified to allow higher throughputs thanks to advanced power amplifier and signal processing technologies. In a GPRS (or EDGE) cell, traffic is split between voice (on circuit) and data (on packet). Data uses a few dedicated circuits which are decomposed into 20 ms blocks carrying elementary packet traffic. EDGE uses adaptive modulation and coding, thus it differs from the GPRS that it can also adapt the modulation scheme, and due to the fact that in many occasions EDGE service is not available due to high BER or limitation of network resources, therefore only the GPRS/GSM data performance is considered as the worst case analysis here.

Earlier studies of GPRS performance [4] and [5] focus on the protocol behavior with a fixed number of channels used for data transmission. However, the number of channels available to GPRS is a random variable depending on the voice traffic and the voice channels' occupancy, thus the service statistics is a movable boundary Markov process [6]. The analysis of GPRS performance is a complicated problem especially as multiple classes of quality of service and multiple classes of users are supported in GPRS. In the study here, the GPRS performance, e.g., the blocking probability and average queuing time, in the variable resource is evaluated by an approximation method. Only single slot GPRS is assumed in this study for the ease of analysis, and on the other hand it's sufficient to evaluate the performance of worst case scenario.

For the developed prototyping wireless remote control and monitoring system, it has been designed to utilize hybrid communication means in order to improve its reliability performance of wireless communication. Figure 1 illustrates a single terminal model of improved reliability performance with reduced blocking probability. Let P_{Bp} donate the blocking probability of using packet switched access i.e. GPRS/EDGE and P_{Bc} donate the blocking probability of using circuit switched access i.e. CSD/HSCSD. Assume that a remote access attempt firstly tries to connect with packet switched access with blocking probability $P_{Bp} = 0.05$, if it is blocked then secondly tires to connect with circuit switched access with blocking probability $P_{Bc} = 0.01$, if it is again blocked then we consider that this remote access attempt has failed due to the blocking from network. It can be easily obtained that the overall blocking probability of such system is $P_{Bp} \cdot P_{Bc} = 0.05 \times 0.01 = 5 \times 10^{-4}$, which is already very small. Even this is for using single terminal case, and the overall blocking probability will be further reduced with double redundant terminal case (with physical independent network service providers), which can be estimated as $(P_{Bp} \cdot P_{Bc})^{2} = 2.5 \times 10^{-7}$. The system is designed in such a way that it will always automatically reconnect in case the connection is blocked or dropped, therefore the overall blocking probability discussed here is also applicable to evaluate the blocking probability of the system for regaining access to the network.

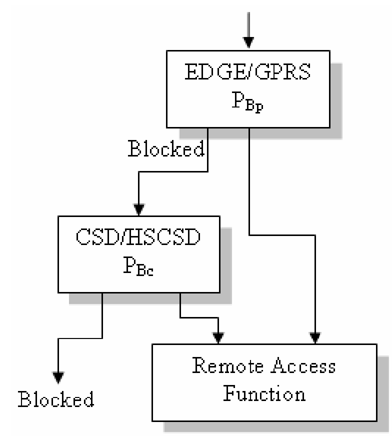

Figure 1. Hybrid model with reduced blocking probability

4. System model for performance evaluation

According to [7], for a system with m physics channels, m_v channels are shared by voice and data services and m_d channels are dedicated to data, as shown in Figure 2. In the pool of m_v channels, when channels are not used by voice services, those channels are used for GPRS transmission. The voice services own preemptive priority over GPRS, i.e., whenever channels used by the GPRS service are needed by voice services, the GPRS transmission in those channels is suspended until some channels are available for GPRS. The users with interrupted service have higher priority for resource allocation than those in queue.

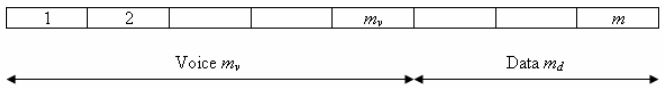

Figure 2. Radio resource allocated to GSM and GPRS

Assume that voice users' arrival is a Poisson process with a rate of λ_v and the call service time is exponentially distributed with a mean of $1/\mu_v$. All GPRS users share the physical channels unused by the voice services. The arrival of GPRS users is assumed to be a Poisson process with rate λ_d and the service time is exponentially distributed with a mean of $1/\mu_d$. The maximum number of users accepted into the system (in service and queue) is N. GPRS calls are served according to the first in first out principle. The arriving GPRS user is allowed to transmit data if a sufficient number of free channels is available; otherwise it is queued or blocked.

5. Approximation method for performance analysis

The voice services are independent of GPRS. Because GPRS is mainly designed to transmit intermittent and burst data, the service time of GPRS is rather smaller than that of voice services. As an approximation, the decomposition technique can be used to analyze the GPRS performance [8]. The essential of this technique is to use the voice services probability distribution to describe the interaction of voice services to GPRS. Thus, the GPRS performance in the dynamically variable resource is obtained by combining this distribution with the performance in a fixed resource.

For the voice services, the probability of n users in service (no queuing) is:

$$r_n = r_0 (\frac{\lambda_v}{\mu_v})^n \frac{1}{n!}, n = 0,1,...,m_v \tag{1}$$

where

$$r_0 = \left[\sum_{n=0}^{m_v} (\frac{\lambda_v}{\mu_v})^n \frac{1}{n!} \right]^{-1}$$

For voice services there are always m_v channels available no matter how many channels are occupied for data services. Since voice services always have higher priority than data services, data users will be forced to suspend their connections and give resources to the voice users. Therefore the blocking probably for voice services is the probability that all m_v channels are occupied by voice users, which is:

$$P_v = r_0 (\frac{\lambda_v}{\mu_v})^{m_v} \frac{1}{m_v!} \tag{2}$$

The channels unused by the voice services may be used for the data services. The probability of x channels available for the data services is equal to that of m_v-x channels used by voice services and is obtained as by (1):

$$g(x) = r_0 (\frac{\lambda_v}{\mu_v})^{m_v - x} \frac{1}{(m_v - x)!}, x = 0,1,...,m_v \tag{3}$$

For the transmission of single slot GPRS in a fixed number of C channels, the average queuing time can be obtained from the *M/M/C/N* queuing system, where N is the maximum number of data users in the network (in service and in queue). The steady-state probability p_n is:

$$p_n = \begin{cases} p_0 \dfrac{\rho^n}{n!}, n < C \\ p_0 \dfrac{\rho^n}{C! C^{n-C}}, C \le n \le N \end{cases} \tag{4}$$

where n is the number of users in the system, $\rho = \lambda_d/\mu_d$, and

$$p_0 = \left[1 + \sum_{n=1}^{C-1} \frac{\rho^n}{n!} + \sum_{n=C}^{N} \frac{\rho^n}{C! C^{n-C}} \right]^{-1}$$

A new arrival is accepted into the system only if the number of data users in the network is below the maximum accepted number N. Otherwise, the new arrival is blocked. The blocking probability is:

$$P_N(C) = p_0 \frac{\rho^N}{C! C^{N-C}} \tag{5}$$

The average number of user in the system is obtained as:

$$\begin{aligned} W(C) &= \sum_{n=1}^{N} n p_n \\ &= p_0 (\sum_{n=1}^{C} \frac{\rho^n}{(n-1)!} + \frac{C^C}{C!} \sum_{n=C+1}^{N} \frac{n \rho^n}{C^n}) \end{aligned} \tag{6}$$

Combining (3) with (5) and (6), the average blocking probability and average queuing time of single slot GPRS in a dynamically varied resource are obtained as following expressions respectively:

$$\overline{P_d} = \sum_{x=0}^{m_v} g(x) P_N(x + m_d) \tag{7}$$

$$\overline{T_d} = \frac{1}{\lambda_d (1 - \overline{P_d})} \sum_{x=0}^{m_v} g(x) W(x + m_d) - \frac{1}{\mu_d} \tag{8}$$

Combining (2) with (7), the overall blocking for this particular system with hybrid communication means of single terminal is obtained as:

$$\begin{aligned} \overline{P} &= P_v \overline{P_d} \\ &= r_0 (\frac{\lambda_v}{\mu_v})^{m_v} \frac{1}{m_v!} \cdot \sum_{x=0}^{m_v} g(x) P_N(x + m_d) \end{aligned} \tag{9}$$

6. Numerical evaluation

In the numerical evaluation, 4 carriers, i.e., 4×8=32 channels in a cell are assumed, from which 1 channel m_d is reserved for data and 31 channels m_v are shared by circuit switched services and data. When a new circuit switched call arrives, if no free channel is available and the number of circuit calls in service is below 31, one of data calls is suspended in order to allocate one channel to the new circuit call. When resources are available, the interrupted data calls have higher priority to allocate resource than the queuing calls. The maximum number of users allowed into network N is 40.

Figure 3 shows the blocking probability of voice services and data services and Figure 4 shows the overall blocking probability of hybrid GPRS/CSD. From the figures it can be seen that such hybrid GPRS/CSD communication means is very effective in reducing the overall blocking probability.

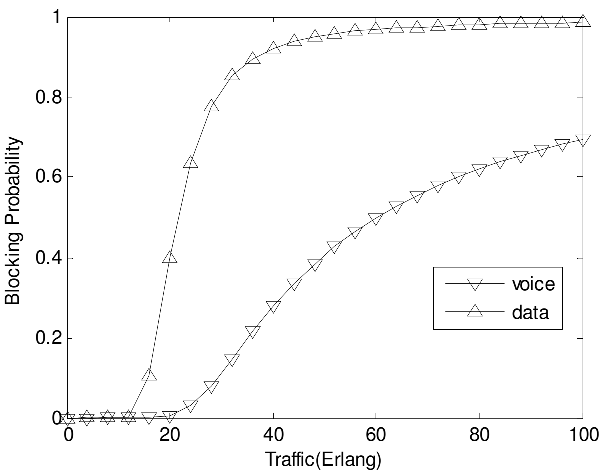

Figure 3. Blocking probability of voice and data

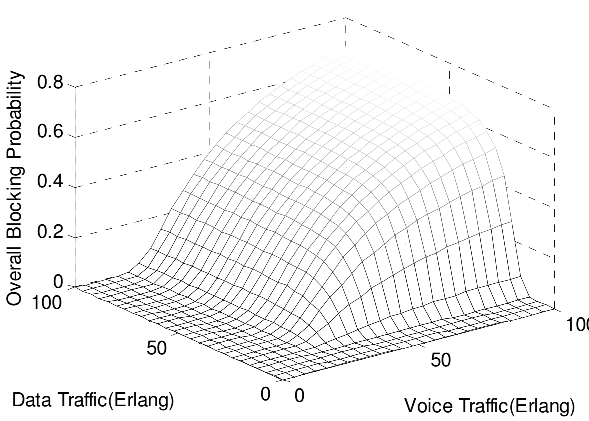

Figure 4. Overall blocking probability of hybrid system

7. Conclusion

In this paper, we present a redundant design with hybrid communication means scheme for implementing reliable wireless communication links for reliability-demanding application of remote control and monitoring system based on current available commercial wireless communication networks. The reliability enhancement over wireless networks has been proposed and studied. The reliability performance of the remote access system using commercial wireless communication network has been analytically and numerically evaluated, and has shown that the demanded reliability can be met using only commercial wireless communication networks.

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