Reliability Modeling of Embedded Nodes in Real Time Wireless Systems

Anandita Sarkar, Jadavpur University, Kolkata, India
Chandreyee Chowdhury, Jadavpur University, Kolkata, India
Sarmistha Neogy, Jadavpur University, Kolkata, India

ABSTRACT

Nowadays there is an increasing trend of applying wireless technologies in industrial automation. However, the industrial control environment is harsher and noisier posing more stringent requirements on real-time communication. The variation in wireless signal strength with time and location, and power limitation due to battery usage make the problem even worse. Accordingly, availability and reliability of such system should be seriously analyzed before deployment. Modeling the reliability of these distributed real-time systems with nodes having embedded software has become an integral part of the design process. The time constraints that real-time systems must meet directly affect the reliability measure itself irrespective of the nature of the measure. A metric for calculating system reliability is proposed in this paper and a Monte Carlo simulation based algorithm for calculating the same is presented here. The results show that system reliability stabilizes with time even with increasing network size.

Keywords: Common Cause Failure, Individual Component Failure, Monte Carlo, Real Time System, Reliability, Sensor Network

1. INTRODUCTION

Embedded computing systems have become a pervasive part of daily life. Over the past decade, we have come to rely on real-time embedded systems in time-critical, safety-critical and mission-critical applications such as electronic stability control for automotive safety, fly-by-wire in avionics and infusion pumps in medical instrumentation (Mangharam, 2008). Recently, two radical transformations are observed in the integration of embedded computing with physical processes. First, they are becoming more and more networked (Dougherty et al., 2011). Secondly, there is a need for tighter interaction with physical systems. There are
several fundamental difficulties in delivering robust real-time services across multiple wireless links. The barriers include:

- Time-varying channel capacity and application demand;
- Uncoordinated interference across the shared wireless channel which makes communication unreliable (mangharam, 2008);
- Lack of global time synchronization across large node populations;
- Limited memory of the embedded devices; and
- Energy constraints of devices.

While mission-critical embedded applications raise obvious reliability concerns, unexpected or premature failures in even non-critical applications can erode a manufacturer’s reputation and greatly reduce widespread acceptability of new devices (Narayanan & Xie, 2006). Moreover as compared with wireless community networks, industrial control environment is harsher and noisier, thus escalating the need for real-time communication. The variation in wireless signal strength with time and location, and power limitation due to battery usage make the problem even worse. Usually, support for wireless communication is given by IEEE 802.11 LAN standard (O’Hara & Petrick, 2009). This standard can only provide best effort service, though there is a mode (Point Coordination Function) that tries to provide time-bound service. In spite of all this, it still remains extremely challenging to provide real time support on top of such MAC layer. Accordingly, availability and reliability of such wireless real time process control system should be seriously analyzed before deployment.

Characteristics of different kinds of distributed wireless embedded systems are discussed in Section 2. In Section 3 state of the art of reliability calculation for such systems are presented. This is followed by a brief discussion on failure model of such system and assumptions (in Section 4). In Section 5 the model for reliability calculation is presented with examples and algorithms. This is followed by simulation results in Section 6. The paper is concluded in Section 7.

2. PROPERTIES OF DISTRIBUTED REAL-TIME EMBEDDED WIRELESS SYSTEMS (DREW)

As mentioned in the previous section, in most of the real time embedded systems, achieving end-to-end quality of service (QoS) is essential (Sivanti & Killat, 2007; Dougherty et al., 2011). Real-time and embedded systems are becoming complex with every passing day and hence their usages have also changed. In particular, real-time and embedded systems are connected via wireless and wired networks to create large scale Distributed Real-time and Embedded (DRE) systems, such as tele-immersion environments, fly-by-wire aircraft, industrial process automation, and total ship computing environments (Schmidt et al., 2004). These DRE systems include a number of interdependent levels, such as network/bus interconnects, many coordinated local and remote end-systems, and often multiple layers of software, that together put forward the following challenges (Schmidt et al., 2004):

- As distributed systems, DRE systems require capabilities to manage connections and message exchange between heterogeneous networked devices;
- As real-time systems, DRE systems require predictable and efficient control over system resources especially network bandwidth in order to provide QoS support;
- As embedded systems, DRE systems have size, weight, cost, and power constraints that often limit their lifetime and computational capabilities;
- As wireless distributed systems, DREW systems are inherently noisy and harsh as environmental noise affects system performance quite often even when the embedded nodes are static. One such example is that of a wireless sensor network.
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