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行政院國家科學委員會專題研究計畫成果報告

RFID-based 人員及物件追蹤管制系統平台之研發--
子計畫(三)：系統平台網路整合與
性能監控技術之研發(I)†

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Abstract

In this paper, the networking architecture of RFID systems is proposed and studied by applying the protocol delay analysis to evaluate the system performance. The key topic of this paper is focused on developing the networking interface technology for RFID readers to construct a ubiquitous system platform. The RFID system platform must possess the interoperable performance to integrate the different hardware and software. The networking interface of RFID readers is implemented by ARM-based embedded system to build the internet protocol in the operating system of uClinux. The feasibility evaluation of system performance is demonstrated by integrating the reader and the PC server using Ethernet protocol. In conclusion, a system-level platform is proposed and tested to illustrate the networking integration for RFID systems.

Keywords: RFID system, networking architecture, ubiquitous system platform, networking interface, embedded system.

1. Introduction

Radio Frequency Identification (RFID) systems have recently become very popular in many service industries, purchasing and distribution logistics, industry, manufacturing companies and material flow systems. The information about people, animals, goods and products in transit is also provided by the EPC codes stored in RFID tags. RFID system plays an increasingly important role in object-tracking and inventory management systems, since RFID system may be built as an integrated platform on which users can implement different applications simultaneously. Therefore, a system-level approach is greatly required to achieve the networking integration for RFID systems.

Due to the evolution of RFID systems, the technology of automated identification system has the great breakthrough. In the past, the traditionally manual identification systems can only read a barcode data once. So far, through the contactless technologies of radio-frequency sensing, the readers of RFID systems have already taken the multiple data of electronic tags at the same time, hence the performance of identification systems have greatly updated such as the reading velocity, capability, and distance. The electronic tags may store the bulk data and possess the long lifetime for using. The tolerance of tags and the identification ability of readers for the harsh environments are very superior. In conclusion, the advantages of RFID system include increasing the identifying efficiency and accuracy, enlarging the reading distance and range, and bringing the routine usage convenience. Therefore, the technologies of RFID systems will be popularly applied to the daily livings and the commercial activities [1].

While the RFID system is widespread, the electronic tag is a great deal of usage such as the entrance guard system and product management system. Thus the data processing and the used disposal of the tags are the key factors of RFID applications. On the other hand, the electronic product code (EPC) stored in tags should possess the properties of unique code for the product identification and networking for internet spreading. In order to the convenience of data management and searching, the integrated RFID system is greatly required to construct the networking architecture of RFID system [2]. In this paper, the networking architecture of RFID system is proposed and studied by applying the protocol delay analysis to evaluate the system performance. The networking architecture of RFID system is introduced and discussed in Section II. Section III presents the networking analysis of embedded system readers. The networking interface of RFID readers is developed by ARM-based embedded system to implement the internet functions. It is followed that the firmware interfaces of ARM-based embedded system readers are designed and implemented in Section IV. The feasibility evaluation of system platform is demonstrated by integrating the reader and the PC server using Ethernet protocol. The testing results are also discussed. Finally, the conclusion is given in Section V.

2. Networking Architecture of RFID System

The networking architecture of RFID system based on EPC standards consists of the readers, Savant, PML Server and ONS Server depicted as Figure 1. Via the transmission protocol of radio-frequency technology, the readers receive continuously the tag data in the front-end of RFID networking system. The received data are transfer to the savant computers. Since the bulk of tag data may contain the duplicated or invalid data, the Savant host plays a role of data filter to catch the significant information. By the extraction of savant computer, the data quantity is decreased in the back-end of network and the system performance is further increased [2][3].

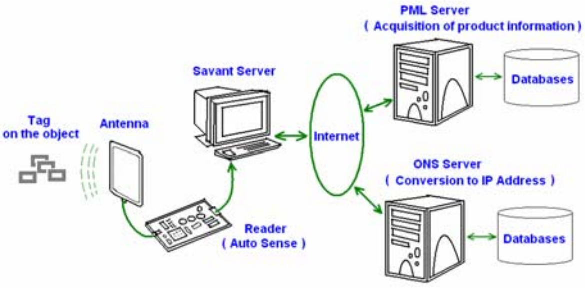

Figure 1. Networking Architecture of RFID System Based on EPC Standards [2].

Object Name Services (ONS) Server is used to look for the vendor information of products corresponding to related code in tag's EPC like the function of Domain Name Services (DNS) in the internet. In addition, the Physical Markup Language (PML) Server is used to provide the package format of EPC data including the product database of vendors. When the Savant receives a tag data, through the transformation of the vendor information in the EPC from the ONS Server, the significant EPC data will be sent to the correspondingly physical address of PML Server by the operation of Savant [2][3].

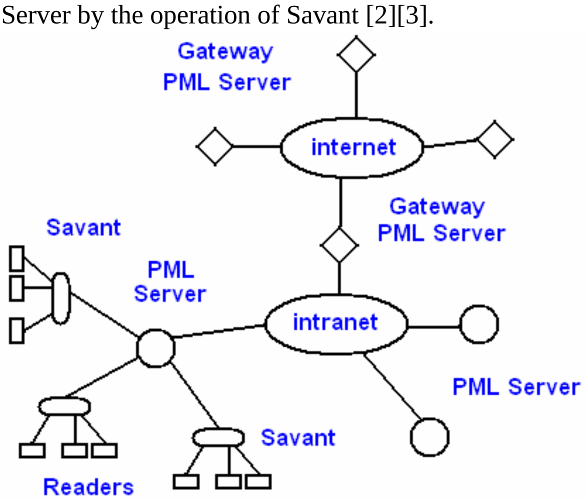

Figure 2. Integrated Networking Architecture of RFID System [4]

The integrated networking architecture of RFID system shown in Figure 2 is described as the organized structure similar to tree-like diagram. The readers get the tag data in the bottom layer of the tree and then send to the Savant host. The Savant computer deals properly with the received data of readers. The useful data be then packed by the PML format and sent to PML server. The PML serves are connected each other by local area network (LAN) and linked up the internet by the Gateway PML server regarded as the window to the outside world. Via the world-wide internet, the integrated RFID networks may construct a ubiquitous system platform to achieve the functions of data management and information communication [4].

3. Networking Analysis of RFID Readers with Embedded System

In this section, the introduction to embedded system is first presented. The networking architecture of RFID readers with embedded system is then proposed and discussed. It is followed that the networking analysis of RFID readers with embedded system is studied by applying the protocol delay analysis to evaluate the system performance.

3.1 Introduction to Embedded System

Embedded System is regarded as the specific application of microcomputer system. Samsung S3C4510B is a 16/32-bit RISC microcontroller with the cost-effective and high-performance solution for Ethernet-based systems and is built around an outstanding ARM7TDMI RISC CPU. The ARM7TDMI core is a low-power, general purpose microprocessor macro-cell that was developed for use in application-specific and custom-specific integrated circuits. The S3C4510B offers a configurable 8K-byte unified cache/SRAM and Ethernet controller which reduces total system cost. Important peripheral functions include two HDLC channels with buffer descriptor, two UART channels, 2-channel GDMA, two 32-bit timers, and 18 programmable I/O ports. On-board logic includes an interrupt controller, DRAM/SDRAM controller, and a controller for ROM/SRAM and flash memory. The System Manager includes an internal 32-bit system bus arbiter and an external memory controller [5].

In order to save the memory space, the uClinux is used as the operating system in the embedded system. The key features of the uClinux different from the Linux are the simplified core and without memory management unit. However, the uClinux is an operating system built-in the internet protocol of the full TCP/IP. In the interfacing design, the Cygwin software is used to serve as the compiler tool of programming developments in the operating system of Embedded uClinux. The executable files generated by Cygwin are downloaded to the target board of embedded system to verify the specified functions of programming.

3.2 Networking Architecture of RFID Readers with Embedded System

The integrated networking architecture of RFID system is depicted in Figure 2 of Section 2. The embedded system is used to implement and experiment one branch of RFID networking system in this paper. The embedded system is treated as the controller of RFID readers to perform the reading operation of tag data. The readers with embedded system must possess the built-in function of internet transmission. Via the internet media, the received data of readers are sent to the system database installed in the PC server or the PML server. Thus the embedded system reader plays the role of the Savant host in the RFID networking system. Figure 3 shows the hardware architecture of RFID networking system based on the readers with embedded system.

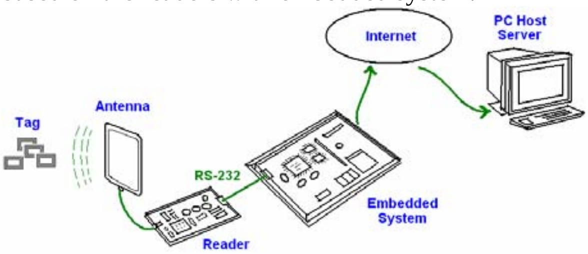

Figure 3. Hardware Architecture of RFID Networking System based on the Readers with Embedded System.

3.3 Analysis Model of RFID Networking System

Quoting from the analysis of protocol delay approach [4], the system performance is evaluated and discussed in this section. It is assumed that the data of 'n' EPC tags are transmitted from one reader to one PC server and the network connection from the reader to the savant and further from the savant to the corresponding PC servers is traced by the standard Internet Protocols. Here, the Query Tree (QT) protocol is used by the reader to read the EPC tags to avoid simultaneous tag reading collisions. The propagation delay is evaluated by the path from the reader to the PC server through the embedded system depicted in Figure 4.

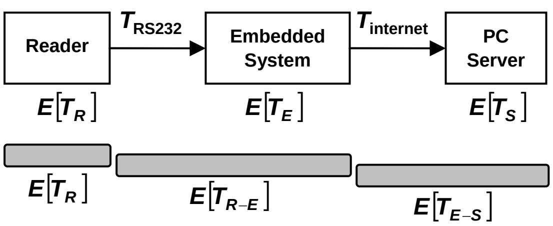

Figure 4. Analysis Model of RFID Networking System.

The transmission delay along the RS-232 lines to send the 'n'-tag data is denoted as T_{RS232}. $E[T_R]$ denotes the expected time to read 'n' tags by the RFID reader and pack the 'n'-tag data as one packet. While the reader receives the transmitting command from the embedded system, the data packet is sent to the embedded system. $E[T_{R-E}]$ represents the expected time taken by the reader to send 'n'-tag packet to the embedded system and the embedded system to process the data. It is expressed by

$$E[T_{R-E}] = T_{RS232} + \frac{E[T_E]}{1-\rho_E} \qquad (1)$$

where ρ_E is defined as the average system occupancy at an embedded system. At this time, the embedded system takes out the significant tag data from the received packet and judges the validity of the tag data. $E[T_E]$ which expresses the holding time at the embedded system is given by

$$E[T_E] = p \times T_{E1} + (1-p) \times T_{E2} \qquad (2)$$

where p is the probability that a packet containing 'n' tags has at least 1 new tag and is thus not dropped. T_{E1} and T_{E2} are, respectively, the service times at the embedded system for packets which contain at least 1 new tag and for packets which are dropped.

Similarly, $E[T_{E-S}]$ denotes the expected time taken by the embedded system to send the valid tag data to the PC server and the PC server to process and display the data. It is given by

$$E[T_{E-S}] = P \times \left(T_{Internet} + \frac{E[T_S]}{1-\rho_S} \right) \qquad (3)$$

where ρ_S is defined as the average system occupancy at the PC server. $E[T_S]$ denotes the expected time taken by the PC server to process and display the tag data and $T_{Internet}$ is the transmission delay take by the internet path.

Considering standard internet protocol, the overall transmission delay sending 'n'-tag data from the reader to the PC server is calculated. The total delay equation is expressed by

$$T_{total} = E[T_R] + E[T_{R-E}] + E[T_{E-S}] \qquad (4)$$

4. Networking Interface of RFID Readers with ARM-based Embedded System

The hardware descriptions of used readers and tags are first introduced in this section. The control interface between the reader and the embedded system is studied and designed for the RFID networking system. Eventually, the reader's networking interface is implemented by ARM-based embedded system.

4.1 Hardware Introduction to Readers and Tags

Regarding the communication standard between the reader and electronic tag, there are two international organizations, EPCglobal and ISO, for the global standardization of RFID systems. The EPCglobal establishes the Electronic Product Code (EPC) standard mainly used in the frequency range of UHF. The ISO organization defines the ISO 14443 A/B and ISO 15693 standards for the 13.56MHz frequency and ISO 18000 standard for the

860~930MHz frequencies, respectively [6].

The electronic tags used in this study are followed by ISO 15693 standard and contain the built-in 64-bit read-only Unique Identifier (UID) to store the unique code of tag data. The coding format of UID depicted in Figure 5 consists of the 6-byte unique serial number (bit0~bit47), the 1-byte manufacturer code (bit48~bit55) and the 1-byte prefix code ("0xE0") [7].

8 bit	8 bit	48 bit
64 ~ 57	56 ~ 49	48 ~ 1
E0	Manufacturer code	Unique serial number

Figure 5. UID Coding Format [7].

The communication interfaces of the readers may be connected by the RS-232, RS485, LAN or USB port. The MR100 made by the FEIG ELECTRONIC is used as the reader of RFID networking system and its operating frequency is at 13.56MHz. The hardware diagram of MR100 is shown in Figure 6. The output of MR100 is connected to the host computer by RS-232 serial port [8].

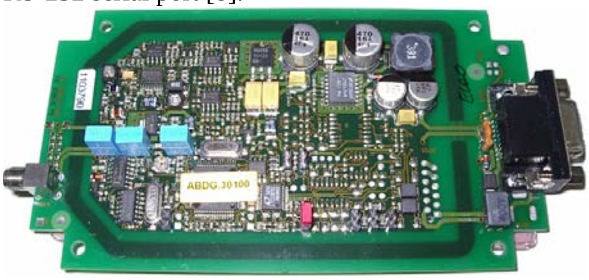

Figure 6. Hardware Diagram of MR100. (Data Source: [8])

4.2 Control Interface between Reader and Embedded System

The communication format between the MR100 reader and the host is carried out by the handshaking approach. The operations of MR100 reader follow the control commands of the host by the fixed format of instructions. After the executions of the reader, the results such as the tag data will be sent to the host. The interfacing protocol between the reader and the host is described in Figure 7.

If there are no tags in the induction range of the reader, the status without available tags is transmitted to the host. Nevertheless, if more than one tag is detected and read, the UID codes of the tags will be packed as one packet and then sent to the host computer. The data format of the packet with three UID codes is shown in Figure 8 [8].

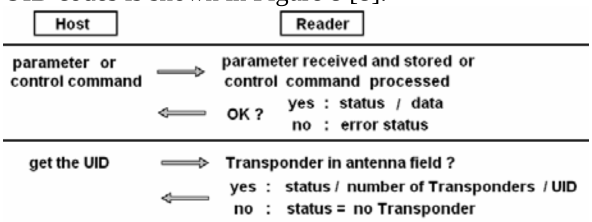

Figure 7. Interfacing Protocol between MR100 Reader and Host [8].

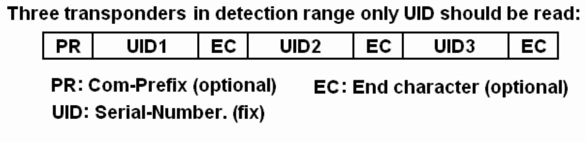

Figure 8. Data Format of the Packet with Three UID codes [8].

4.3 Implementation of Reader's Networking Interface

The ARM-based embedded system is used to control the operations of the reader and to implement one branch of RFID networking system in this section. First, the reset function of RF antenna is executed by the command of the embedded system through the MR100 reader [8]. The embedded system is waiting until the response from the reader is received. The reader is then operated in normal mode for reading the tags. Via the reader, the tag data is continuously detected and sent to the ARM-based embedded system by the RS-232 serial port. The embedded system processes properly the received data from the reader and takes out the significant UID data from the received packet. In order to decrease the data amount, the embedded system judges the validity of the tag data and sends the useful data to the PC server via the world-wide internet. The PC server further analyzes the data and displays the required information.

The hardware architecture of RFID networking system based on the readers with embedded system is described as Figure 3. The driving program of embedded system is developed by C language in Cygwin software. The executing flow of system program is depicted in Figure 9.

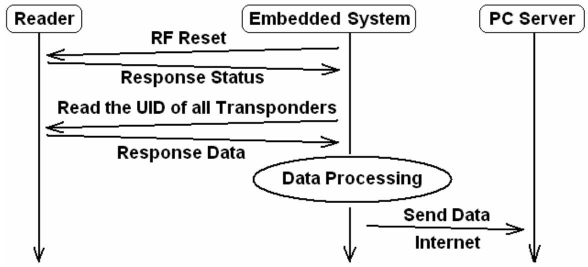

Figure 9. Executing Flow of System Program [8].

The TCP/IP is the most popular communication protocol in the internet. The concept of TCP/IP protocol is comprised of the network access layer, the internet layer, the transport layer and the application layer. The core of TCP/IP protocol is based on the internet layer and the transport layer. The Internet Protocol (IP) is the transmission approach of TCP/IP and responsible for processing the data packet and deciding the transmitting path of the packet. The TCP protocol is responsible for the message division and provides the internet linkage for the data transmission. In general, the connections between the hosts may simultaneously execute several processes in multi-tasking operating system. The TCP protocol provides the required ports to execute the different processes while the IP address only represents the host itself [9]. Figure 10 shows the transmission ports of TCP protocol.

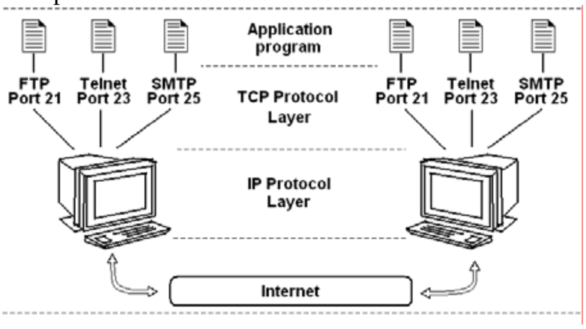

Figure 10. Transmission Ports of TCP Protocol. [9]

Via the internet, the linkage between the embedded system and PC server is implemented by the programming interface of networking sockets. The socket interface is one of the Application Programming Interfaces (API) which are the media between the application program and the transmission protocol in the internet. Figure 11 describes the socket interface of the TCP/IP protocol. The internet programming provides the class library of socket function to support the program development of designers. In the application of embedded systems, the built-in function "socket()" is used to create the new port of the communication socket in the operating system of uClinux. The uClinux gives the operating ID as the socket identifier for the executing procedure. Moreover, the data structure of the socket address , which including the communication protocol, the TCP connection stream of the data transfer and the IP address and port number used, must be defined in the internet application. Besides, it also need to set socket address data structure for internet, which it include the communication protocol used the Internet, TCP connection stream socket data kinds of the data transfer, the IP address and Port number. After the socket has been created, the library function "connect()" is used to set the IP address of the IP layer and the port number of the TCP layer to connect with the PC server [9].

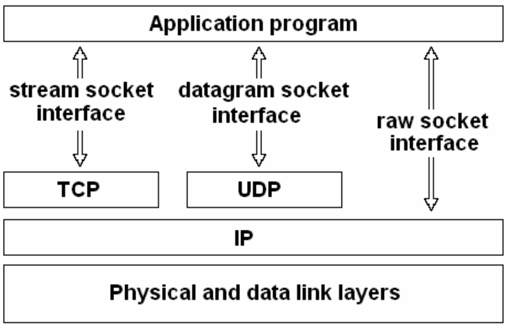

Figure 11. Socket Interface of TCP/IP protocol. [9]

While the socket interface is successfully connected to the PC server through the TCP/IP network, the UID data of the tags in the embedded system are sent to the PC server and then stored in the stack memory. The encapsulation and decapsulation of TCP/IP data is described in Figure 12. In addition, the built-in function "send()" allows the embedded system to transmit data to the PC server. While the data will be delivered, the processes of data packing on each layer are called "encapsulation." On the other hand, while the data have been received, the processes of data unpacking on each layer are called "decapsulation." The data format of TCP/IP transmission for encapsulation and decapsulation is also observed in Figure12 [9].

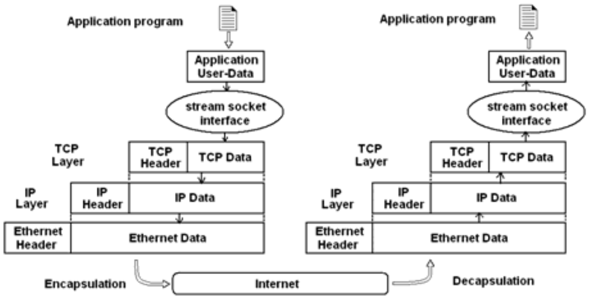

Figure 12. Encapsulation and Decapsulation of TCP/IP Data [9]

The target board operated in uClinux is enabled and driven by the developed program downloaded through the FTP/NFS connection in the internet. The implemented hardware environment of RFID networking system with embedded system is illustrated by the organization diagram of Figure 13. In Figure 13, the medium and right sides show the reader and the antenna of MR100 and the left side is the target board of the embedded system. The two RS-232 ports of the target board is used to connect to the reader for reading the tag data and the PC host for developing the interface program, respectively. The received data in embedded system are transmitted to PC server by the Ethernet connection. Figure 14 shows the display interface of the embedded system in the executing mode. In this situation, there are four tags sensed by the reader. The seven-segment LED displays the amount and the LCD panel exhibits the UID codes of the detected tags, respectively.

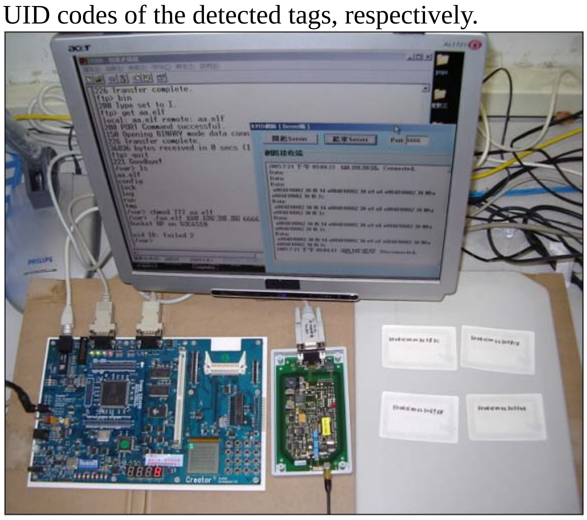

Figure 13. Implemented Hardware Environment of RFID Networking System with Embedded System.

Figure 14. Display Interface of Embedded System in Executing Mode.

Regarding the interface of PC server, the application program is developed by the integrated development environment of Borland C++ Builder. It is very simple to design the internet program since the Borland C++ Builder supports the built-in functions of the Server/Client socket for system development. The developed interface of PC server for data receiving is depicted in Figure 15. The received data of four tags in Figure 15 are transmitted from the embedded system showed in Figure 14 through the Ethernet interface.

Figure 15. Operating Interface of PC Server

5. Conclusions

The networking architecture of RFID systems is proposed and studied to construct a ubiquitous system platform in this paper. Based on the Query Tree (QT) protocol and applying the analysis of the protocol delay approach, the system performance of the networking RFID system with embedded system is discussed and evaluated. The networking interface of RFID readers is developed by ARM-based embedded system to implement the control interface between the reader and the embedded system, and the internet protocol between the embedded system and the PC server, respectively. In conclusion, the feasibility evaluation of system platform is demonstrated by the integrated networking architecture of RFID system with the ARM-based reader using Ethernet protocol. The ARM-based reader operated by uClinux may execute the multi-tasking functions and possess the Ethernet connection for the system networking. Thus the embedded system reader with the Savant function becomes portable and intelligent in the RFID networking system. Therefore, it is the preferred reader for the better performance requirement of RFID system. Finally, a system-level environment is proposed and tested to illustrate the networking integration for RFID systems in this paper.

6. References

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