Design and Implementation of an OA&M System for WLL Network

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Abstract: **This paper describes the design and implementation of an OA&M system for DECT-based WLL network. This system follows the client-server architecture that enables remote management through the Internet. Object-oriented design is used to yield quality software, where the entire WLL network is treated as a hierarchical collection of objects. The "plug-in" mechanism provides the capabilities of replacing and extending OA&M functionalities in run-time. Design patterns are applied to improve the reusability of software components. Two types of user interfaces are implemented in different platforms to provide access to the OA&M system. Although our design is tailored for the WLL network, it is also appropriate to serve as the OA&M system for other small-scale telecommunication systems.**

Index Terms: **Wireless local loop, OA&M, DECT.**

I. INTRODUCTION

Wireless local loop (WLL) provides two-way calling services to the stationary or "fixed" users, which is intended to replace its wireline counterpart. In the recent years, WLL is considered as an alternative to wireline access for the telephony services. Compared with the wireline local loop, the WLL offers advantages such as ease of installation & deployment, and concentration of resources [1], [2].

On the other hand, since WLL involves radio resource allocation, management of WLL has higher complexity than its wireline counterpart. Thus, *OA&M (operations, administration, and maintenance)* for WLL is more critical than that for wireline local loop. Through OA&M, the WLL network is operated, administered and maintained by a network operator. For a large wireless telecommunication network, OA&M is typically implemented following *Telecommunication Management Network (TMN)* specification [3]–[8]. Such an approach is too heavy for small-scale systems. This paper demonstrates the design and implementation of OA&M for a small-scale WLL system. Our design is also appropriate for other small-scale telecommunication systems.

Fig. 1 presents the WLL architecture developed by Eumitcom Technology Inc. In this architecture, the *base station controller (BSC)* is responsible for interfacing the WLL network to local exchange (LE). The connections between a BSC and the LE are tip/ring lines (or T1) with a concentrator. The *radio base station (RBS)* acts as the wireless access point for the *radio network termination (RNT)*. The air interface between the RBS and the RNT follows the ETSI *Digital Enhanced Cordless Telecommunications (DECT)* standard [9]. The RNT is responsible for converting and delivering the voice and control signaling between the CPE (through subscriber telephone lines) and the RBS (through the DECT air interface). The *CPE (customer premise equipment)* is typically a telephone set. The *concentrator* performs concentrating and mapping functions between 576 lines in the LE and 64 lines in a BSC. The dashed area illustrates the OA&M system (WLL-OAM) for the WLL network. WLL-OAM monitors the WLL network remotely through Internet.

We describe a design and implementation of WLL-OAM for small-scale WLL network. This paper is organized as follows. Section II discusses the OA&M management functions for WLL. Section III presents the WLL-OAM architecture. Section IV describes the communication protocols for WLL-OAM. Section V discusses the WLL-OAM software design. For the reader's benefit, Table 1 provides an acronym list used in this paper.

II. WLL OA&M MANAGEMENT FUNCTIONS

The WLL OA&M system provides the OA&M services to control and monitor the equipment in the WLL system. The network elements managed by WLL-OAM are BSC, RBS, RNT, and CPE. Five types of OA&M management functions are provided in WLL-OAM.

1) *Type 1:* The *network configuration* functions report the configuration information of the WLL.
2) *Type 2:* The *network element status* functions monitor the status of the WLL network elements.
3) *Type 3:* The *failure detection* functions detect the errors/failures occurring in the WLL network elements.
4) *Type 4:* The *testing* functions test the functionalities and qualities of the network elements.
5) *Type 5:* The *call statistics* functions provide call performance of the WLL network.

For BSC, the Type 1 function is *system configuration* that provides the topology information for the WLL network, including equipped RBSs and registered RNTs connected in the network. The Type 2 function is *BSC information* that includes the BSC ID, date/time, bootstrap indication, etc. The date and time of a BSC are used to synchronize the time-related information between the OA&M system and the BSC. Bootstrap indication records the time when the BSC is re-booted. The Type 3 function is *board failure detection* that reports the circuit board fail-

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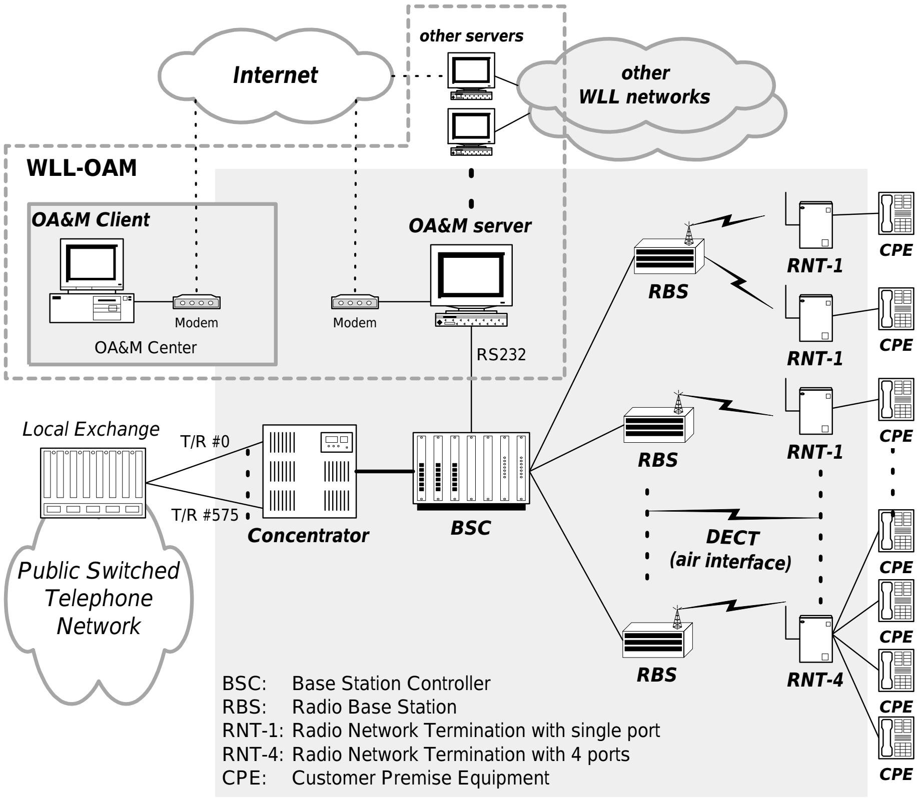

Fig. 1. The wireless local loop.

Table 1. Acronyms.

BSC	base station controller
CI	command interpreter
CPE	customer premise equipment
DECT	Digital Enhanced Cordless Telecommunications
DLL	dynamic-link library
DOC	distributed object computing
DTP	data transfer process
GUI	graphical user interface
MEI	message-exchange interface
OA&M	operations, administration, and maintenance
RBS	radio base station
RNT	radio network termination
STL	standard template library
TCP/IP	Transmission Control Protocol/Internet Protocol
UCI	user-command interface
UML	Unified Modeling Language
WLL	wireless local loop

ures in the BSC. When the OA&M system detects a failure, it alerts the operator. The Type 4 function is *loopback test* used to verify the availability of transmission between the OA&M system and the BSC.

For RBS, no Type 1 function is defined. The Type 2 function is *RBS information* including the RBS ID, channel assignment, etc. The Type 3 functions include *power failure detection* and *RBS failure detection*. The Type 4 function is *RBS loopback test* that verifies the availability of the transmission between the RBS and the BSC.

For RNT, the Type 1 functions include *registration* and *deregistration* that allow an RNT to attach and detach the WLL system. The registration function authenticates an RNT, and the deregistration function cancels authority of an RNT. The Type 2 functions include *RNT information* and *CPE presence detection*. The RNT information includes the RNT ID, attached CPE ID, registration status, DECT identities, password, etc. The CPE presence detection helps the operator to confirm whether the unreachable calling service is caused by the customer. The Type 3 functions include *power failure detection* and *low battery voltage detection* that allow the OA&M system to detect power failure and abnormality of backup battery. The Type 4 functions include *ring/ring trip test*, *tone generation test*, and *RNT loopback test*. The ring/ring trip test instructs the RNT to ring the CPE. This test verifies the availability of transmission between the BSC and the CPE. The tone generation test instructs the RNT to generate a tone to the CPE. The tone patterns include *dial tone*, *busy tone*, *ring tone*, etc. This test helps the operator to verify the tone generation functions on the RNT. The loopback test verifies the availability of transmission between the RNT and the BSC. The Type 5 functions perform *statistics of call attempts*, *RSSI (received signal strength indication) measurement*, and *FER (frame error rate) detection*. The call statistics includes the number of successful call attempts, the number of dropped call attempts, and the number of blocked call attempts. The operator uses this information to reallocate wired and wireless resources in network planning. The RSSI indicates radio signal strength received by the RNT during a call conversation. The

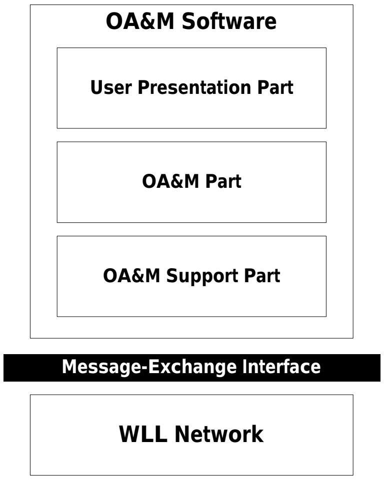

Fig. 2. OA&M software architecture.

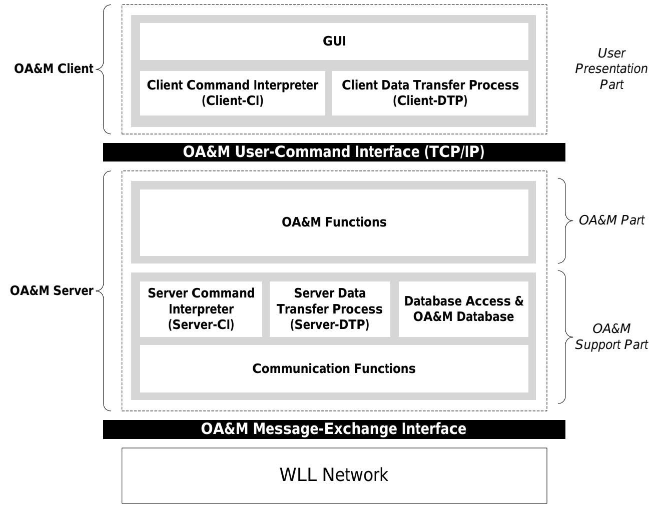

Fig. 3. Modules of the client-server-based WLL-OAM architecture.

FER value is measured to evaluate the radio link quality during a call conversation.

III. THE WLL-OAM ARCHITECTURE

Fig. 2 illustrates a common OA&M software architecture consisting of three parts: *user presentation part*, *OA&M part*, and *OA&M support part* [10].

The user presentation part provides a man-machine interface to the OA&M system. The OA&M part provides the primary OA&M management functions to monitor and control the WLL network. The OA&M support part provides database access functions, communication functions, and other miscellaneous functions. The OA&M system exchanges messages with the WLL network through *message-exchange interface (MEI)*.

The WLL-OAM design follows the *client-server* approach where the software is separated into two parts: *OA&M client* and *OA&M server*. The OA&M client is responsible for user presentation, which provides a graphical user interface (GUI) for OA&M users. The OA&M server passively waits for requests from OA&M clients and then provides the OA&M services to the clients. The OA&M client and the OA&M server exchange messages through a TCP/IP application-level protocol called *user-command interface (UCI)*. Fig. 3 illustrates the details of the client-server-based WLL-OAM architecture. In this architecture, the OA&M client consists of three modules: *graphical user interface interface (GUI)*, *client command interpreter (client-CI)*, and *client data transfer process (client-DTP)*. The GUI provides a friendly interface to the operator. The client-CI is responsible for transferring UCI commands, and the client-DTP is responsible for transferring OA&M data.

The OA&M server consists of six modules: *OA&M functions*, *server command interpreter (server-CI)*, *server data transfer process (server-DTP)*, *database access functions*, *OA&M database*, and *communication functions*. The OA&M functions control, monitor, test, and debug the WLL network. The server-CI "listens" on a certain TCP port for a connection requested from a client-CI and then establishes a control session. It receives commands from client-CI through UCI, sends the corresponding replies for the commands, and then governs the server-DTP for data transfer. The server-DTP establishes a connection on demand from server-CI and then transfers data to and from the client-DTP through this connection. The database access functions retrieve and store data in the OA&M database. The OA&M database contains the information for system configuration, RNT registration, OA&M data, etc. The communication functions provide the capabilities of communication with the WLL network.

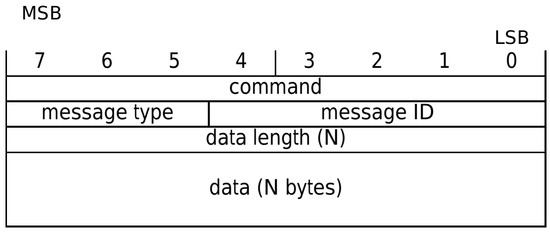

Fig. 4. MEI message format.

IV. COMMUNICATION PROTOCOLS

Two communication protocols are developed in WLL-OAM: The message-exchange interface (MEI) and user-command interface (UCI). The MEI interfaces the OA&M server with WLL networks. The UCI supports communication between OA&M clients and the OA&M server.

A. OA&M Message-Exchange Interface

OA&M MEI is a reliable serial communication protocol, which exchanges OA&M messages between WLL-OAM and a BSC. The MEI message format is shown in Fig. 4. The 8-bit *command* is used to specify OA&M service. Some of the MEI commands are listed in Table 2. The *message type* indicates the type of a message, which can be *request*, *response*, or *trap* (to be elaborated later). The *message ID* is used to distinguish the outstanding messages so that more than one message of the same MEI command can be issued simultaneously. The message ID is used by the OA&M server to correlate incoming responses with the corresponding outstanding requests. The *data length*

Table 2. An incomplete list of MEI commands.

Message Type	*Command*	*Description*
Request-response	OAM_BSC_CONFIG	BSC configuration (ID, topology information, etc.)
	OAM_BSC_LOOPBACK	loopback test for BSC
	OAM_DEREG_RNT	deregistration of RNT
	OAM_GET_DATE	retrieval of date/time for BSC
	OAM_LINK_QUALITY	link quality detection (frame error rate)
	OAM_RBS_CONFIG	RBS configuration (ID, channel assignment, etc.)
	OAM_RBS_LOOPBACK	loopback test for RBS
	OAM_REG_RNT	registration of RNT
	OAM_RING_TRIP	ring/rint trip test
	OAM_RNT_CONFIG	RNT configuration (ID, password, IPUI, IPEI, etc.)
	OAM_RNT_LOOPBACK	loopback test for RNT
	OAM_RSSI	RSSI value of RNT
	OAM_SET_DATE	date/time setup for BSC
	OAM_TONE_GEN	tone generation test
	OAM_UPDATE_BSC	BSC configuration update
	OAM_UPDATE_RBS	RBS configuration update
	OAM_UPDATE_RNT	RNT configuration update
Trap	OAM_BSC_BOOT	BSC booting indication
	OAM_BSC_FAILURE	notification of BSC failure (board failure)
	OAM_RBS_FAILURE	notification (power failure, RBS failure, etc.)
	OAM_RNT_FAILURE	RNT event notification (power failure, RNT failure, etc.)
	OAM_STATISTICS	call statistics (dropping, blocking calls, etc.)

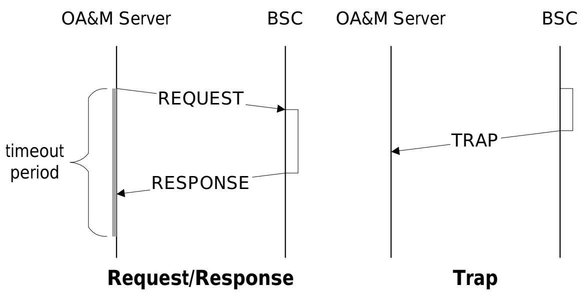

Fig. 5. MEI transmission paradigm.

indicates the length of *data* in bytes. Since the bit length of the *data length* field is 8 bits, the data length is limited to 255 bytes and the total message length is limited to 258 bytes (255 bytes plus 3 bytes for message header).

As shown in Fig. 5, two kinds of transactions are defined in the MEI transmission paradigm: *request-response* and *trap*. The request-response transaction is used by the OA&M server to retrieve the WLL information. The WLL (specifically, the BSC) utilizes traps to inform the WLL-OAM of significant events.

In a *request-response transaction*, the OA&M server sends the *request messages* to the BSC to invoke some OA&M routines, and the *response message* acknowledges the corresponding request message. Every request-response transaction is associated with a timeout timer controlled by the OA&M server. If the timer expires, the transaction is regarded as a failure. The message type of a request message is OAMMT_REQUEST, and the message type of a response message is OAMMT_RESPONSE. Both request and response messages in a request-response transaction have the same message ID.

Trap messages are issued from a BSC without any acknowledgement, which allow the OA&M system to receive asynchronous notification of significant events in the WLL network. A trap message is of the type OAMMT_TRAP. Different trap operations are distinguished by their command names. The message ID field is ignored in a trap message.

B. OA&M User-Command Interface

The *user-command interface (UCI)* supports communication between the OA&M server and multiple OA&M clients. The UCI is a TCP/IP application-level protocol compliant to Internet Telnet protocol [11]. UCI transmission mechanism is similar to Internet File Transfer Protocol [12], which uses two TCP connections to transfer OA&M information.

1. The *control connection* is used for UCI command transmission. This connection is established in the normal client-server fashion. That is, the OA&M server performs a passive open[1] on the port for OA&M and waits for a connection from an OA&M client. The client performs an active open to the OA&M port to establish the control connection. The control connection stays up during the client-server communication session. The command interpreters (CIs) are responsible for managing the control connection.
2. The *data connection* is created when the OA&M data are transferred between a client and the server. The data transfer processes (DTPs) are responsible for managing the data connection.

Table 3 shows the nine commands defined for OA&M client. Table 4 shows the three UCI commands defined for OA&M server.

C. Examples of OA&M Information Exchange

This section gives two examples for OA&M information exchange. The first example utilizes the request-response transaction paradigm, which is illustrated in Fig. 6 (a) with the following steps.

[1] In TCP/IP terminology, the side that sends the first TCP packet with SYN flag set is said to perform an *active open*. The other side, which receives this TCP SYN package and sends the next TCP SYN package, performs a *passive open*.

Table 3. UCI commands for client.

Command with optional parameters	*Description*
`ABOR`	aborting previous UCI command and any data transfer
`ACTN` *action parameters*	performing an action
`GETD` *item parameters*	retrieving OA&M data
`HELP`	help menu for human reading only
`NOOP`	no operation (intended to test the control connection)
`PASS` *password*	password
`QUIT`	logout from the server
`SETD` *item parameters*	storing OA&M data
`USER` *username*	username

Table 4. UCI commands for server.

Command with parameters	*Description*
`PORT` *n1,n2,n3,n4,n5*	indicating IP address (*n1.n2.n3.n4*) and port (*n5*)
`RPLY` *code description*	acknowledgement of the client command
`TRAP` *category time code from description*	notifying significant events

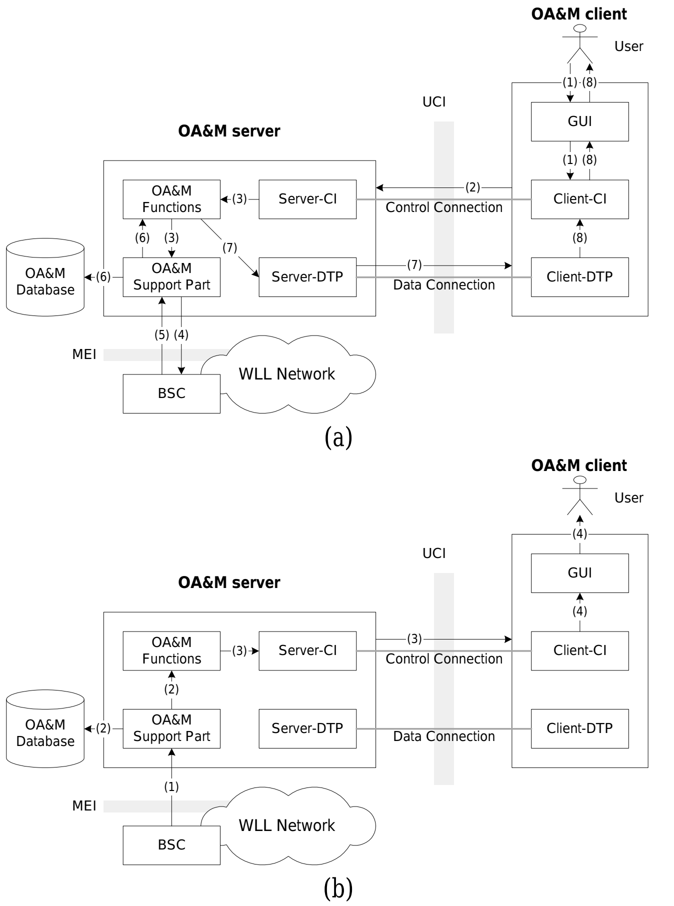

Fig. 6. OA&M information exchange: (a) OA&M data access, (b) significant event notification.

Step 1 – The user issues a UCI command through the GUI of the OA&M client.

Step 2 – This command is generated by client-CI, and is sent to the OA&M server via the UCI control connection.

Step 3 – The server-CI invokes the OA&M functions to execute the command.

Steps 4–6 – The OA&M functions utilize the OA&M support part to retrieve the OA&M data from the BSC via MEI and then stores the data in the OA&M database.

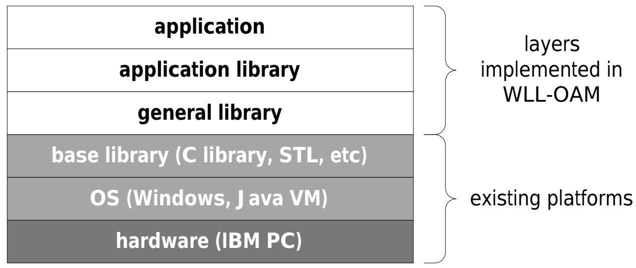

Fig. 7. Layers in WLL-OAM design.

Steps 7 and 8 – The OA&M server uses server-DTP to transfer the data to the client via the UCI data connection. Finally, the client-DTP receives the data and the GUI presents the data to the user.

The second OA&M information exchange example shows how a BSC issues a trap to the WLL-OAM. The example is illustrated in Fig. 6 (b) with the following steps.

Step 1 – The BSC raises a trap to the OA&M server through MEI.

Step 2 – The OA&M support part receives the trap, stores it to the OA&M database.

Step 3 – The OA&M server invokes OA&M functions to process this trap and instruct server-CI to send the results to the OA&M client via the UCI control connection.

Step 4 – The client logs the trap and displays it on the trap page to alert the user.

The details for GUI, client-DTP, server-DTP, OA&M functions, and OA&M support part will be discussed in the next section.

V. OA&M SOFTWARE DESIGN

The WLL-OAM design follows object-oriented approach where the entire WLL network is treated as a hierarchical collection of objects managed by the OA&M system. We also apply the *design patterns* [13] concept in WLL-OAM to provide reusable designs and architecture (to be elaborated later).

The WLL-OAM design is structured in layers as shown in Fig. 7. The *hardware platform* is IBM PC, and the *operating*

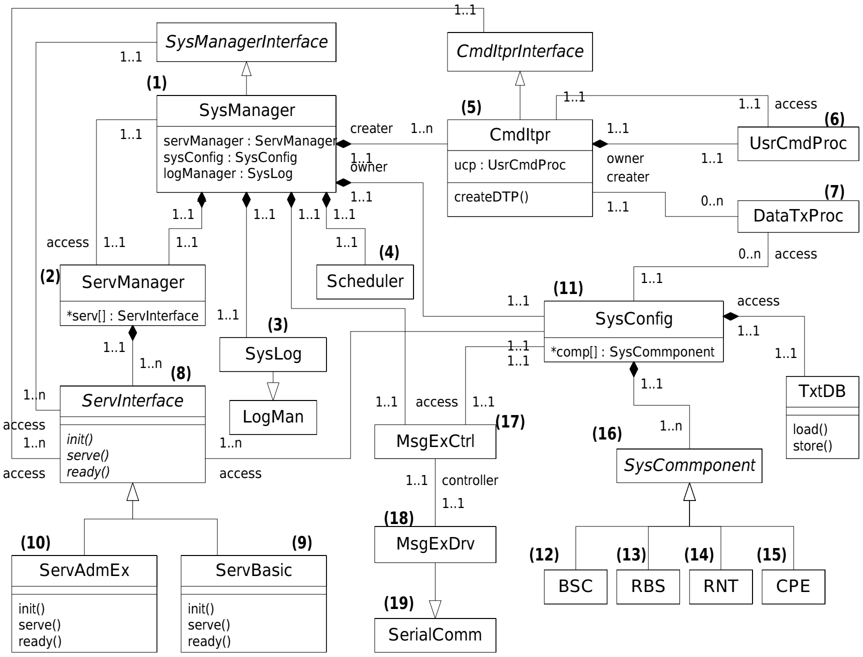

Fig. 8. Class diagram of OAMserv.

system is Microsoft Windows or Java VM. The standard C library and C++ *standard template library (STL)* are used as the base library for WLL-OAM implementation. The WLL-OAM *general library* includes general functions for database access, debugging, logging facility, statistics, etc. The *application library* provides OA&M specific functions such as serial communication classes, UCI-model classes, "service plug-in" mechanism, system configuration class, scheduler, etc.

WLL-OAM consists of an OAMserv (OA&M server) and several OAMclis (OA&M clients). The client-server model helps WLL-OAM to decentralize the user interface from the OA&M functions. OAMserv and OAMcli may be distributed into two independent programs running on different hosts. The client is responsible for the user interface, and the server is responsible for the OA&M functions. Both the client and the server can extend their functionalities autonomously. A client can have different styles for user interface, ranging from a plain command-line interface to a fancy graphical interface, which would not affect the performance or correctness of the server.

In the current WLL-OAM version, we have implemented two styles of OAMclis: OAMst and OAMjava. OAMst is a stand-alone application implemented in C++ and OAMjava is a web-based application implemented in Java. OAMjava is a portable Java applet program, which provides the web-based OA&M management for the WLL network. The user can use a general web browser (e.g., Netscape or Internet Explorer) to operate OAMjava.

A. OA&M Server Design

Fig. 8 illustrates the *UML (Unified Modeling Language)* class diagram [14] of OAMserv, which consists of a collection of classes listed in Table 5. These classes are grouped into six categories: *system management*, *OA&M service plug-in*, *OA&M service management*, *MEI communication*, *UCI communication*, and *WLL information management*. In the OA&M architecture in Fig. 3, the OA&M functions are implemented by the OA&M service management classes. To provide convenient OA&M service management, the OA&M service plug-in classes are designed to support service "plug-in" mechanism (to be discussed in Section V-A.2). The message-exchange functions are implemented by the MEI communication classes, the server-CI and the server-DTP are implemented by the UCI communication classes. The database access and OA&M database are implemented by the WLL information management classes. The *system management class* organizes all classes in OAMserv.

The concept of design patterns are used to implement the OA&M server classes. Design patterns are descriptions of communicating objects and classes customized to provide reusable designs and architectures. The design patterns utilized in the server design include: Singleton, Facade, State, Observer, Iterator, etc.

A.1 System Management Class

The `SysManager` (system manager) object ((1) in Fig. 8) is created immediately after OAMserv is executed. This object is responsible for coordinating the following OAMserv objects. A `ServManager` (service manager) object manages the available OA&M services ((2), Fig. 8). A `SysConfig` (system configuration) object organizes the OA&M data ((11), Fig. 8). A `MsgExCtrl` (MEI controller) object exchanges OA&M messages with a BSC through the MEI protocol ((17), Fig. 8). A `SysLog` (system log) object logs the significant information of WLL system ((3), Fig. 8). A `Scheduler` object periodically invokes management routines ((4), Fig. 8). In addition, some `CmdItpr`

Table 5. The server classes.

Category	*Class*	*Description*
System management	`SysManager`	System manager

OA&M service plug-in	`ServInterface`
	`ServBasic`
	`ServAdmEx`
		Service interface (abstract class)
		Basic services for WLL OA&M
		Extended administration services

OA&M service management	`ServManager`	Service manager
MEI communication	`MsgExCtrl` `MsgExDrv`	MEI controller MEI driver

UCI communication	`CmdItpr`
	`UsrCmdProc`
	`DataTxProc`
		Command interpreter
		User command process
		Data transfer process

WLL information management	`SysConfig`
	`SysComponent`
	`BSC`, `RBS`, `RNT`, and `CPE`
	`SysLog` and `Scheduler`
	`TxtDB`
		System configuration
		System component (abstract class)
		BSC, RBS, RNT, and CPE
		System log and OA&M scheduler
		Text-based database management

(command interpreter) objects are dynamically created to establish the UCI control connections for new clients ((5), Fig. 8).

Since `SysManager` is the kernel of OAMserv, the *Singleton* pattern is utilized in the `SysManager` class to ensure that this class only has one instance with a global point of access.

A.2 OA&M Service Plug-in Classes

OAMserv treats a set of OA&M functions as a "service plug-in." The service plug-in can be attached to or detached from OAMserv dynamically. A new OAMserv function can be efficiently extended by attaching a service plug-in through `ServInterface` (service interface).

The `ServInterface` class ((8) in Fig. 8) is an abstract class[2] that provides a unified interface for OA&M service plug-ins. In our current design, there are two subclasses of `ServInterface`: the `ServBasic` ((9), Fig. 8) class that provides the OA&M management functions (e.g., RSSI measurement) and the `ServAdmEx` class ((10), Fig. 8) that provides extended administration functions (e.g., server shutdown) for OAMserv. Fig. 9 illustrates the relationship between OAMserv and the service plug-ins. *Facade* pattern is utilized by service plug-ins to provide a unified interface (i.e., `ServInterface`) to OAMserv [13]. Facade pattern promotes loose coupling between OAMserv and its plug-ins, so that the modification on a service plug-in does not affect the OAMserv.

In the OAMserv design, a service plug-in is a *dynamic-link library (DLL)* in Microsoft Windows. A DLL is an executable file that acts as a shared library of functions. Dynamic linking allows a process to call a function that is not part of its executable code. With DLL, the classes in the OAMserv design are *build-time modular*, and the service plug-ins are *run-time modular*. The service plug-in design reduces the cost for upgrading software. Detaching the old plug-in and attaching the new one do not require re-compiling the whole software and can be done in run-time.

A.3 OA&M Service Management Classes

The `ServManager` object ((2), Fig. 8) is a Singleton object created by `SysManager` when OAMserv is executed.

[2]An abstract class is a class whose primary purpose is to define an interface. It defers some or all its implementation to subclasses, and it cannot be instantiated.

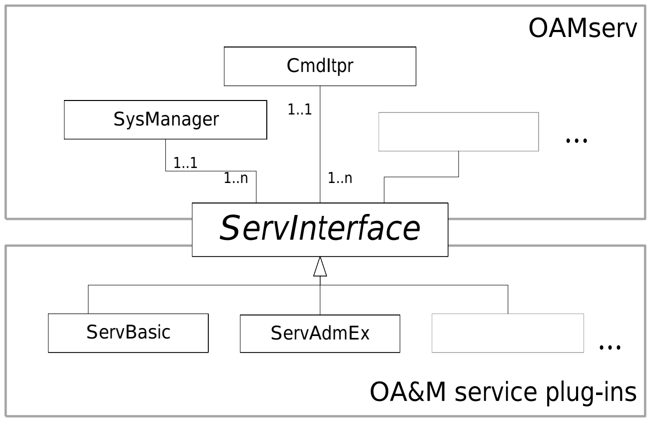

Fig. 9. The Facade pattern concept in the OAMserv design.

`ServManager` manages the OA&M services implemented by the classes derived from `ServInterface` ((8), Fig. 8). The `SysManager` object invokes the OA&M functions by querying the services from the `ServManager` object.

A.4 MEI Communication Classes

The MEI is implemented by the `MsgExCtrl` class ((17), Fig. 8) for communication with a BSC. The `MsgExCtrl` object aggregates an `MsgExDrv` object ((18), Fig. 8) to enable serial communication via an RS232 port with a BSC. The `MsgExDrv` (MEI driver) class inherits the the RS232 communication capability from a general-purpose class called `SerialComm` ((19), Fig. 8).

When the `MsgExCtrl` receives a trap message, it ripples through the `ServManager`, `SysConfig`, and `CmdItpr` objects to handle this trap. *Observer* pattern is applied to these classes, which defines a one-to-many dependency between objects so that when one object changes state, all its dependencies are notified and updated automatically [13].

A.5 UCI Communication Classes

When an OA&M client connects to the server, a control connection is established and a `CmdItpr` (command interpreter) object at the server is created to operate on this connection. The `CmdItpr` object ((5), Fig. 8) interprets the UCI commands

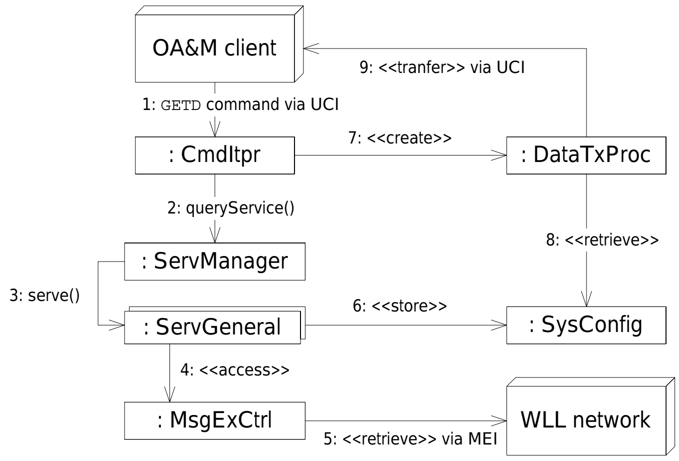

Fig. 10. Interaction diagram for the GETD command.

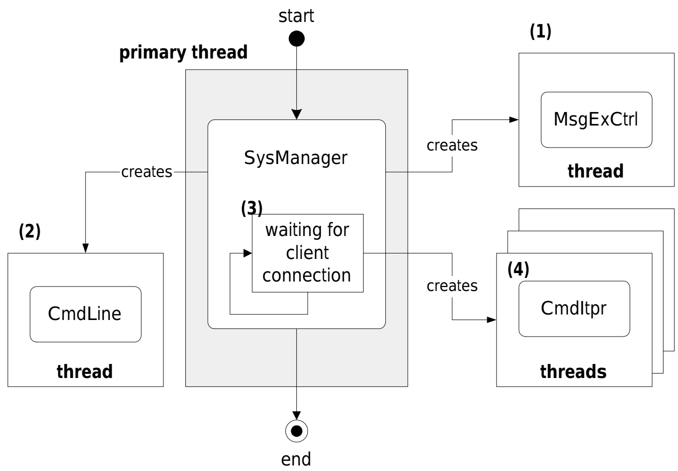

Fig. 11. Multithreaded programming in OAMserv.

from the client, and its `UsrCmdProc` object ((6), Fig. 8) executes these commands. When a data transfer is required, a `DataTxProc` (data transfer process) object ((7), Fig. 8) is dynamically created to handle the corresponding data connection. *State* pattern is applied on the UCI implementation. This pattern allows an object to alter its behavior when its internal state changes [13]. As an example, Fig. 10 shows the interaction diagram[3] of a `GETD` command.

Step 1 – When an OA&M client issues a `GETD` command via UCI, the `CmdItpr` object in the OA&M server receives this command.

Step 2 – The `CmdItpr` object invokes the `queryService()` method to search the service plug-in (e.g., a `ServBasic` object) that handles this command.

Step 3 – The `ServManager` object calls the `serve()` method of this plug-in to perform service function.

Steps 4 and 5 – The `ServGenernal` object instructs `MsgExCtrl` object to retrieve the OA&M data via MEI.

Steps 6–9 – The OA&M data are stored in the `SysConfig` object. Finally, the `CmdItpr` object creates a `DataTxProc` for transferring data.

A.6 WLL Information Management Classes

As we mentioned in Section II, four WLL network elements are managed by WLL-OAM. The OA&M data for these network elements are implemented by the `BSC` class ((12), Fig. 8), the `RBS` class ((13), Fig. 8), the `RNT` class ((14), Fig. 8), and the `CPE` class ((15), Fig. 8). These classes inherit from the abstract class `SysComponent` ((16), Fig. 8). The OA&M data maintained in a `SysComponent` object are related to the management functions described in Section II. For example, a *RNT* object contains RNT ID, password, call statistics, registration status, etc.

The `SysConfig` class ((11), Fig. 8) is intended to manage these objects, which supports *object persistence* for its managed objects. This persistence mechanism automatically stores an object to a persistent storage device (hard disk, for example) to retain the state of this object that may be retrieved later. When the `SysConfig` object is created by `SysManager`, it performs the persistence function to load the system configuration from database into memory.

The `BSC`, `RBS`, `RNT`, and `CPE` classes inherit the persistence capability from their base class `SysComponent`. The persistent data are stored in the OA&M database, which is a file-based database managed by the `TxtDB` class. The data in the `TxtDB` database are stored in the plain-text (ASCII) format that allows porting to various software/hardware platforms.

The OA&M data in a `SysConfig` object must be consistent with that in the WLL network. A *cache* mechanism is included in the `SysConfig` design to minimize the communication overhead between the OA&M server and a BSC.

A.7 Multithreaded Programming

OAMserv is implemented on the *Win32* environment (Microsoft Windows 95/98/NT) using preemptive multitasked and multithreaded programming. The use of multiple threads provides modular design for WLL-OAM. As shown in Fig. 11, when the main program of OAMserv is executed, the *primary thread* (for `SysManager`) will create a thread to control the MEI (by `MsgExCtrl`class; see Fig. 11 (1)) and another thread to process command-line inputs (using `CmdLine` class; see Fig. 11 (2)). The primary thread then binds a TCP port and waits for client connection ((3), Fig. 11). For each client, it creates a thread to maintain a UCI session ((4), Fig. 11).

B. OA&M Client Design

Fig. 12 illustrates the UML class diagram of OAMcli, which consists of a collection of classes listed in Table 6. These classes are grouped into three categories: *GUI classes*, *UCI communication classes*, and *UCI command classes*. In the OA&M architecture in Fig. 3, the GUI is implemented by the GUI classes. The client-CI and the client-DTP are implemented by the UCI communication classes. The UCI commands and the WLL information management are implemented by the UCI command classes.

[3] A UML interaction diagram illustrates a set of objects and their relationships, including the messages that may be dispatched among them [14].

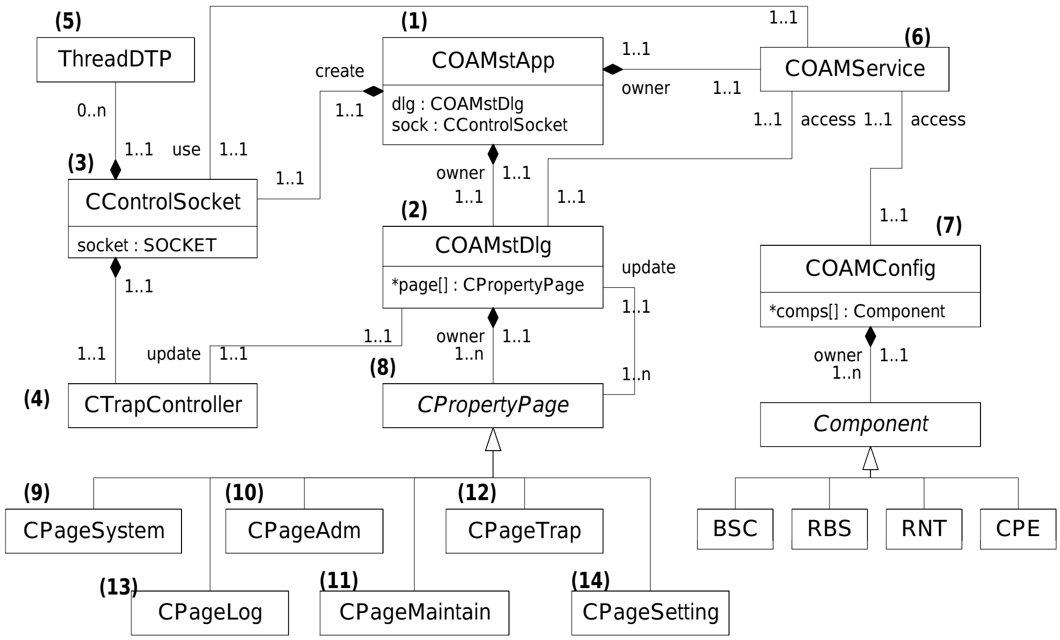

Fig. 12. Class diagram of OAMcli.

Table 6. The client classes.

Category	*Class*	*Description*

GUI classes	`COAMstApp`
	`COAMstDlg`
	`CPageSystem`, `CPageAdm`,
	`CPageMaintain`, `CPageLog`,
	`CPageTrap`, and `CPageSetting`
		OAMst application
		OAMst dialog box
		System page, administration page, maintenance page, log page, trap page, and setting page.

UCI communication classes	`CControlSocket`
	`ThreadDTP`
	`CTrapController`
		UCI control socket
		Client-DTP thread
		Trap controller

UCI command classes	`COAMService` `COAMConfig`	OA&M services OA&M configuration

B.1 GUI Classes

`COAMstApp` ((1), Fig. 12) is the main class that aggregates other classes in OAMcli, including `COAMstDlg` (main dialog) class for the user interface ((2), Fig. 12), `CControlSocket` (UCI control socket) class for UCI ((3), Fig. 12), `CTrapController` (trap controller) class for the OA&M traps ((4), Fig. 12), `COAMService` (OA&M services) class for OA&M services ((6), Fig. 12), etc.

The `COAMstDlg` class implements the main dialog box that contains several pages for various OA&M categories. The pages are implemented by the GUI page classes derived from `CPropertyPage` ((8), Fig. 12). These page classes provide contents for OA&M user interface, including `CPageSystem` ((9), Fig. 12) for system view, `CPageAdm` ((10), Fig. 12) for administration, `CPageMaintain` ((11), Fig. 12) for maintenance, `CPageTrap` ((12), Fig. 12) for OA&M traps, `CPageLog` ((13), Fig. 12) for system logs, and `CPageSetting` ((14), Fig. 12) for miscellaneous settings.

A GUI derived from OAMcli is protected by a login/password mechanism. The system-view page provides a hierarchical OA&M information of the WLL network, including BSC, RBS, RNT, and CPE. Each level of the OA&M information is associated with a floating menu. This menu provides the access to the corresponding scope of OA&M. The *administration page* provides the OA&M data retrieval. The *maintenance page* provides the capability for testing. The *trap page* is used to monitor the WLL network. The *logging page* is used to record some significant information. The *setting page* is used to set IP address, port, user name, GUI parameters, etc.

B.2 UCI Communication and Command Classes

The client-CI is implemented in the `CControlSocket` class ((3), Fig. 12), which is responsible for controlling UCI. The client-DTP is implemented in the `ThreadDTP` objects ((5), Fig. 12), which is dynamically created for data transfer.

The `CTrapController` class deals with traps sent from the OA&M server. It notifies the `COAMstDlg` object of the occurrences of traps, and the `COAMstDlg` object updates the user interface to alert the user.

The `COAMService` object ((6), Fig. 12) is used to instructs `CControlSocket` to perform the UCI commands via UCI. The `COAMConfig` class ((7), Fig. 12) maintains the WLL information (stored in `BSC`, `RBS`, `RNT`, and `CPE` objects), which is consistent with the OA&M data maintained on the server side.

VI. CONCLUSION

This paper described the design and development of an OA&M system, WLL-OAM, for a DECT-based WLL network. Our design is also appropriate for other small-scale telecommunication systems. Based on the object-oriented approach, the WLL-OAM has the following features.

- The *client-server architecture* provides flexibility and scalability, which supports remote management through Internet or other data networks. Multiple OA&M clients can control and monitor an OA&M server simultaneously.
- *Design patterns* allow reuse of OA&M software designs and architectures.
- *"Plug-in" service mechanism* supports efficient bug fixing and OA&M service feature extensions.
- *Web-based OA&M management* provides portability and ease of installation.

In our implementation, the OA&M server, OAMserv, is a Win32 console-mode[4] application running on Windows 95/98/NT. The current version of OAMserv is about 15,000 lines of C++ codes, and the client OAMcli (including OAMst and OAMjava) is about 20,000 lines of C++/Java codes.

The communication protocol between an OA&M client and the OA&M server is the user-command interface (UCI) implemented by using Windows Sockets (WinSock) programming. In the future, the *distributed object computing (DOC)* will be used to implement the UCI connection management. DOC simplifies network programming with component-based software architecture, and facilitates collaboration of local and remote application components in a heterogeneous distributed environment [15].

In current WLL-OAM implementation, message-exchange interface and user-command interface are proprietary. The WLL-OAM design is intended for network standard compliance. In the future, the proxy architecture will be considered for standard-compliant extension of WLL-OAM, which provides a standard network management interface for the OA&M clients.

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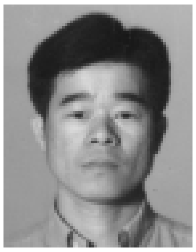

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