System-level design of embedded applications by UML: the Wireless Meter Reading case.

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The Unified Modeling Language (UML) is a language for specifying, visualizing, constructing, and documenting the artifacts of software systems, as well as for business modeling and other non-software systems. The UML represents a collection of best engineering practices that have proven successful in the modeling of large and complex systems; it is interesting to envision its extension for specification and modeling of hardware-software systems as well, since the first design phases, i.e. before hardware-software partitioning has been effected. This paper describes how UML has been used in the design of a wireless meter reading system consisting of hardware and software components.

1 INTRODUCTION

As the complexity of systems increases, so does the importance of good specification and modeling techniques. There are many additional factors for a project's success, but having a rigorous modeling language standard is certainly an essential factor (see, e.g., [1], [2]). In recent years, the Unified Modeling Language, UML, has been introduced and is now widely used, basically for requirements specification in the design of complex software systems. UML does not guarantee project success but it does improve many things. For example, it significantly lowers the perpetual cost of training and retooling when changing between projects or organizations. It provides the opportunity for new integration between tools, processes, and domains. But most importantly, it enables developers to focus on delivering business value and provides them a paradigm to accomplish this.

In the present paper we describe use of UML for specification and modeling of a hardware-software system, carried out at the Advanced Learning and Research Institute (ALaRI: http://www.alari.ch) of the Università della Svizzera Italiana in Lugano (http://www.unisi.ch).[1]

The project refers to design of a **Wireless Meter Reading System (WMR);** it was decided to use **UML** because it meets the following high-level requirements specification:

- It is technology independent;
- It is Hardware/Software partitioning independent;
- It allows specification of both functional and non-functional requirements and constraints;

The advantage of using UML is that it makes the whole designed system highly modular, so that we could structure the whole WMR system as the interconnection of a number of different blocks consisting of Hardware and Software components.

In this paper we will describe the project, the UML implementation and the future perspectives.

2 PROBLEM DESCRIPTION

Wireless Meter Reading is a reading system to help the end user to get the consumer consumption data regarding gas, electricity and water via wireless technology.

2.1 The context

2.1.1 Background

As markets deregulate, WMR solutions become increasingly attractive, and even systems with one

[1] The project constitutes the Master project for a small group of students sponsored by some of ALaRI's industrial partners, namely ABB, ST Microelectronics TXT-e-solutions and AIL; the authors are indebted to Mr. Bruno Sabbattini (ABB), Mr. Jeff Owen (ST Microelectronics), Mr. Flavio Fusetti (TXT-e-solutions) and Mr. Marco Bigatto (AIL) also for stimulating useful discussions and criticism.

energy, gas or water meter, where the meter is traditionally read on site only once per month, can be profitable for commercial and small industrial customers.
Using the analysis of consumption data, any unnecessary consumption can be identified and eliminated faster than before. The time from the reading operation to the generation of the invoice by the energy supply company is reduced and simplified, which in turn reduces administrative costs. Further the WMR system offers an innovative path to transparent details of costs and hence to effective cost savings for all participants.

2.1.2 Objective

Real-time determination of the energy consumption (that is, where, when and to what extent energy is consumed) and Wireless Meter Reading system using wireless technology.

2.1.3 Description of changes

The WMR is a special case of field service that represents such a vast opportunity that it warrants its own category (in fact, this application is well established and it has its own trade group, the *Automatic Meter Reading Association (AMRA): http://www.amra-intl.org*). The vast fleets of vehicles and personnel now engaged in reading utility meters at homes, offices and factories can be replaced entirely by telemetry-equipped meters that read and send meters data automatically. Many utilities are already using telemetry for this purpose, and many more will adopt it as deregulation takes hold state by state and utilities are forced to face new competition.

Many wireless service providers, including a number of private wireless networks, have aggressively pursued this market opportunity. GSM has some advantage comparing to the other networks, primarily its digital foundation and public network cost-effectiveness, apply particularly well in an application such as WMR.

WMR is an interesting opportunity for another reason as well: many large industrial and commercial utility customers and their service providers are starting to explore real-time pricing, energy sell-backs and other flexible options. **Real-time pricing**, for example, can reward users for shifting demand to off-peak times. The catch is that all of these potential service features require real-time data collection and control, and that's where telemetry comes into play. By reading a meter remotely every 15 minutes instead of on site once a month, for instance, a utility can work with customers to shift loads and manage prices. *New York's KeySpan Energy* is a great example of the potential for wireless AMR and process control. By applying wireless telemetry to switch meter collection from a schedule-based system to a demand-based system, the city could nearly triple its average profit per meter, not including wireless equipment and service costs.

Another key advantage of a wireless solution is adding **theft monitoring** through the wireless link; as soon as someone tries to vandalize a meter, the system notifies the police. This reduces both theft costs and the considerable costs of sending service crews out to repair vandalized meters.

Responding to the cost and complexity of both landlines and private communication networks, the utility began installing GSM-based monitoring and control points throughout its gas and electricity network. In addition to attaching GSM modules to its electricity meters, KeySpan uses GSM telemetry to monitor gas pipes and substations. The company is also exploring ways to use telemetry to **dispatch repair crews** and control both gas and electricity distribution systems.

2.2 The project constraints

The constraints of the projects are basically the following:

- security requirements on the wireless data transmission to be ensured;
- very low cost;
- very low power consumption;
- modularity and scalability in order to be ready for alternatives and/or future technologies viz: GPRS and UMTS;
- data format for the transmission;
- measuring point identification;
- measuring point status;
- the time base: there is only one time base for the whole system (standard time DCF 77). A quarter of an hour is the smallest measuring period. Longer measuring time are multiple of a quarter of an hour.
- data storage: analysis of the integration with existing systems at the utility side.

2.3 The operational scenario

2.3.1 The Wireless Meter Reading features

In this section we would like to explain the WMR features. Looking at Figure 1 from left to right you can understand better the system description and data flow. Figure 1 gives a high-level system description of the WMR:

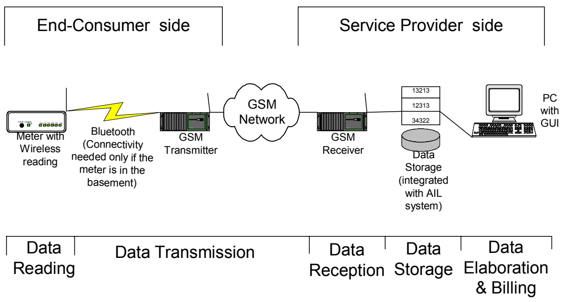

Figure 1: *High-level system description of WMR*

In order to better describe the WMR features, as shown in Figure 1, we divide the system in two susystems meaning the End-Consumer and the Service Provider side.

Features at the End-Consumer side:

- The **data reading** operation can be performed in two different ways depending on the meter type: electronic or mechanical (traditional) meter.
  In the *first case* where, at the End-Consumer side, is installed an electronic meter, then it is sufficient to introduce suitable sensors in order to make the system capable of reading the meter values. In the *second case* (mechanical/traditional meter) the meter reading and radiation can be done using an *Eye Detection Method*: the image of the meter digits is transferred by simple mirror and lens technique to a CMOS image sensor. Both solutions are possible.
- The data will be transmitted using **standard data formats** provided from AMRA, which is an international, nonprofit, association addressing problems of standardization, justification and deployment practices in the application and advancement of enhanced customer-service and resource-management technologies. AMRA offers membership services and educational forums that focus on AMR issues affecting electric, gas and water utility-service companies worldwide.
- The **data transmission structure** does not directly connect the meter to the GSM network, for a number of different reasons. Usually, meters are located in basements, so that the GSM signal reception is very weak or even not present at all. To avoid this problem we considered a transmission architecture using a wireless local area network that brings the data to the GSM transceiver located a few meters away from the basement in a position where there is an acceptable or full GSM signal reception. Using **Bluetooth** could be a good solution to the problem, since it is a low-power and low-cost technology.
- **Bluetooth** is one of the technologies which can be used for **transmitting data** from a given meter location point to the GSM transmitter. Bluetooth devices are high-quality, low-cost and low-power devices: usually the chip-set cost is lower than 10 US$ and each unit is self-powered.
- The **transmission of the metering data** to the Service Provider side can be performed **using GSM technology**. The fragmented nature of the telemetry and telematics markets has given rise to a wide variety of technology alternatives, from low-power radio to landlines. A recurring theme in these markets, however, is that where GSM has been available, it has been widely and successfully employed. The metering data from the Bluetooth can be transmitted to the GSM base station.

Features at the Service-Provider side:

- The **reception of the metering data** is done through the GSM network. One or many stations located at the provider side can be used for receiving this data and monitoring the load.
- The data received will be **stored in a database,** developed ad-hoc for each Service Provider or **integrated** with utility existing system.
- The **data reading** at the utility side is performed from a software interface developed ad-hoc that displays the collected data. In case the utility has already a system in place, this func-

tionality is granted by the integration with the existing system.

2.3.2 The Development Process

UML is a modeling language rather than a methodology. It is largely process-independent, in fact is not tied to any particular development life cycle. However, to get the most benefit from the UML, one should consider a process that is:

- Use Case driven
- Architecture-centric
- Iterative and incremental

This use case driven, architecture centric and iterative/incremetal process can be broken into the traditional Software Development Life Cycle phases, (inception, elaboration, construction and transition) which can be applied very well in the development process of this project.

In order to perform the system partitioning we started from the **Inception Phase** where we collected the system requirements information during meetings organized with the representatives of those companies interested in this project. All the collected information were reported in an Operational Concept Description document which was reviewed by the project team and the companies representitives. The document included also a short description of current systems available in the market (the so called State of the Art).

The Operational Concept Description document was a good starting point to begin the **Elaboration Phase**, which consisted of writing the Hardware and Software Requirements Analysis and Design document including the UML formalization of the system.

Once the elaboration phase was performed we started the **Construction Phase**. The project is still on going and right at the moment of writing the present paper we are completing this phase.

3 THE UML FORMALIZATION

This section describes the use cases and sequence diagrams approaches as well as the advantages and disadvantages by using UML formalization in Hardware/Software co-design.

3.1 The use cases approach

Starting from Figure 1, a first iteraction was to formalize a system scenario using use cases (see: Figure 2). In order to do it we needed to define the system scenarios. A scenario is identified by actors and use cases, so that to represent our system using UML we needed to identify each actor and each use cases playing a role.

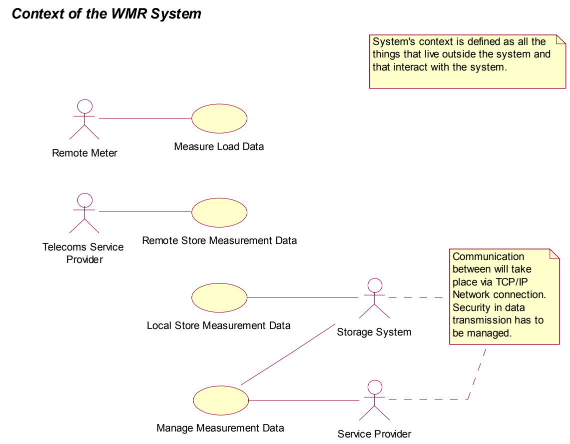

Figure 2: System Analysis with Use Cases

Figure 2 describes the System Overview scenario where actors are:

- the **remote meter** located at the End-Consumer side;
- the **telecom service provider** which provides the telecommunication services for measurement data transmission via GSM network;
- A third party which provides the **Relational Data Base Management System** (RDBMS) located at the Service Provider side;
- **Service** (electricity and/or gas and/or water) **Retailer** which manages all the collected data for load monitoring, billing, real-time pricing and assistance.

and use cases are:

- The meters located at the end-user site measure and collect data load;
- The measurement data coming from the Remote Meters are collected and stored in the GSM Base Station;
- The measurement data coming from the GSM Base Station are collected and stored in the Relational Database (RDB);

- The data collected in the RDB are managed from the Data Reconciliator and the Service Provider.

As described in Figure 2, system's context is defined as all actors live outside the system but interact with it. The communication between storage system and Service Provider takes place via TCP/IP Network connection.

In a second iteraction we splitted the system into two main sub-system component called End-Consumer and Service Provider side.

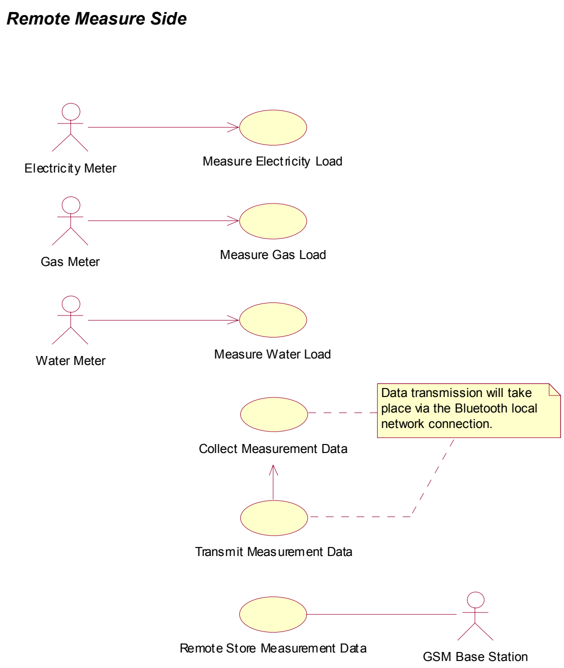

***Figure 3:** End-Consumer sub-system analysis with Use Cases.*

Figure 3 describes the End-Consumer scenario where actors are:

- Electricity, water and gas **meters** at the end-user side;
- **Local base station** which provides server functionalities for the local-area network. It concentrates data coming from the WMR Local Communication Centres (LCC) via the GSM network and provides the interface to the wide-area (TCP/IP) network to communicate with the RDBMS.

and use cases are:

- The meter measures electricity consumption related to each end-user;
- The meter measures gas consumption related to each end-user;
- The meter measures water consumption related to each end-user;
- Load data coming from the WMR Equipments are stored in the WMR LCC.
- Measurement data are transmitted by the WMR Equipments to the WMR LCC;
- The measurement data coming from the Remote Meters are collected and stored in the GSM Base Station.

As described in Figure 3, the data transmission takes place via the Bluetooth local network connection.

3.2 The sequence diagrams approach

The next step that we performed in our development process was the Sequence diagram formalization.

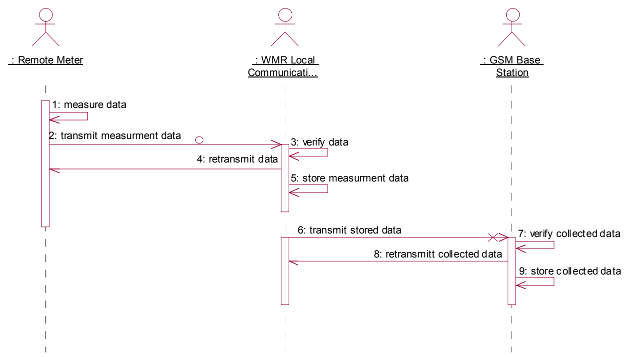

***Figure 4:** System Analysis with Sequence Diagram*

Figure 4 describes the sequence diagram at the System-level, where the Remote Meter, the WMR local communication centre and the GSM base station are objects and the vertical line is the object's lifeline. The lifeline represents the object's life during the interaction. The primary purpose of this diagram is communication between all project stakeholders.

The in Figure 4 represented sequence diagram can be explained as follow:

1. The WMR equipments measure electricity, gas and water data consumption related to the end-user. This operation will occur every 15 minutes using the related sensor on the WMR equipment;

2. The Remote Meter sends the message containing the load measurement data to the WMR LCC via the Bluetooth Local Network. The message will be abandoned if the WMR LCC cannot handle it within a specified amount of time (TIMEOUT MESSAGE SYNCHRONIZATION). This operation will occur every day, after collecting all the information per day. This will be useful for service and load profiling;
3. Received data are processed for transmission errors detection and recovery policies;
4. If the channel shuts down or some errors occur during data transmission the WMR LCC requests data retransmission to the Remote Meters;
5. Measurement data are stored by the WMR LCC before sending them to the GSM Base Station;
6. All measurement data stored in the WRM LCC are sent to the GSM Base Station. Transmission takes place via the GSM Network and with periodicity of one every three months. One possibility is to use the SMS protocol to send the data, or contract with the telecoms company for providing a customised integrated solution for business customers. An other alternative could be GPRS services in which only effective data traffic is paid;
7. Data transmission has to be verified for correcteness and security;
8. If errors occur during data transmission the GSM Base Station requests data retransmission from the WMR LCC;
9. The GSM Base Station stores collected data that will be transmitted to the RDBMS via TCP/IP network.

3.3 Advantages & disadvantages by using UML

The most relevant advantages and disadvantages by using UML formalization are basically identified as follow:

<u>Advantages:</u>

- Help in acquiring an overall view of the system;
- Help in visualizing, specifying, constructing and documenting a hardware/software system;
- Clarity: if at any point, there is confusion over the exact meaning of a particular UML component, reference can be made to the formal description to verify its semantics;
- Consistency: having a precise description of the models, it becomes possible to validate implementations against the design and to check-whether the design fulfills the specifications;
- Correctness feedback: correctness of the model can be achieved through the application of proofs over the formal specifications. Therefore inconsistencies can be detected. A mapping between the model elements of UML to formal specifications can help in adapting proofs and validations to case tools what leads to early detection of errors in the system.
- Easy to add new facilities without big changes in the System Architecture.

<u>Disadvantages:</u>

- Formal specifications are hard to deal with for non-expert users;
- The time needed for the elaboration phase increases and usually the customer, waiting for concrete steps forward, could feel a little bit unconfortable. But, if the system is well designed, the construction and transition phases will be shorter and the high product quality is granted.
- Sometimes a too detailed formalization could create confusion between project stakeholders.

4 FUTURE EVALUATIONS AND PERPECTIVES

In the Pervasive Computing Age, faster, cheaper and more power-efficient alternatives are rapidly evolving for wide-area, indoor, and short-range wireless communication. “Anytime and anywhere access to the Internet” is often quoted as the killer application, fueling much of recent growth in wireless standards and industry.

One of the future evaluations of this project could be a research in the wireless protocol area in order to define a low power-consuming device. In fact, GSM is still too much power consuming for a WMR application.

4.1.1 Field service applications

Apart from metering systems, other applications for the wireless telemetry solution here discussed can easily be identified. Industries and agencies that employ field service crews for monitoring, replenishment or repair represent some of the biggest opportunities for the telemetry market. We can break the applications into 4 categories:

1. ***Systems that need to be refilled***. The humble

vending machine could benefit greatly from wireless telemetry. The current refilling process, which is based on fixed schedules and not on measured demand, now suffers from three major inefficiencies. Telemetry-equipped machines can place orders when needed, with the right mix of products, to optimize sales and minimize replenishment costs.

2. ***Systems that need to be emptied***. Conversely, machines that need to be emptied at unpredictable intervals, such as parking meters and token collection points on mass transit systems, could enjoy the same benefits. In both cases, expensive fleets of vehicles and drivers are employed to service individual transaction points, which individually account for very little revenue but collectively account for very high costs. By matching service efforts with actual, measured demand, both private companies and government agencies can make much better use of their expensive resources.
3. ***Systems that need to be serviced or repaired***. The opportunities in this category range from office machines to railroad crossing barriers to elevators. Whenever a machine in need of attention — particularly a machine involved in generating revenue or keeping people safe — can automatically and immediately call in for service, telemetry is likely to pay for itself many times over. One of the newest applications in this area is tying telemetry transmitters to the uninterruptible power supplies (UPS) connected to critical computing or telecommunications systems. Since the UPS can keep the system running for only a matter of minutes in most cases, the transmitter can alert technicians to shut the system down gracefully or switch to backup power or backup networks.

Other Systems. Telemetry can also be used to monitor HVAC systems, gas and oil pipelines, vending machines, alarm systems, parking meters, streetlights, smoke or fire detectors, factory process systems and photocopiers. Wireless telemetry is also used to provide a variety of vehicle tracking and location services.

An additional benefit of wireless telemetry that applies in all above categories is mobility. For example, a company that leases office equipments could easily move its machinery from one customer site to the next without worrying about installing new phone lines to establish data connections.

5 REFERENCES

[1] D. Harel: "Statecharts: A Visual Formalism for Complex Systems", *Science of Computer Programming*, (8): pp. 231-274, 1987

[2] S.Narayan, F.Vahid, D:d:Gajski: "System Specification with the SpecCharts language", *IEEE Design & Test of Computers*, pp. 6-12, Dec. 1992

[3] M.Fowler, K.Scott: "UML distilled, applying the standard object modeling language", *Addison Wesley,* 1997.

[4] G.Booch, J.Rumbaugh, I.Jacobson: "The Unified Modeling Language User Guide", *Addison Wesley,* 1999.

[5] B.P.Douglass: "Real-Time UML: Developing Efficient Objects for Embedded Systems (2nd Edition)", *Addison Wesley,* 1999.