Remote Building Monitoring and Control

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This project is intended to develop a prototype system which would permit remote monitoring and control of multiple commercial buildings across the Internet from a single control center. Such a system would be used by operators of multiple buildings, such a school districts, governments, universities, large retailers, utility companies, building management firms, et al.

We anticipate that such a system would reduce the labor costs of building monitoring and control and thereby permit more extensive monitoring and control of building HVAC and lighting systems. We estimate that this will generate improvements in building energy efficiency of 15 percent on average.

Phase I of the project involves the following components:

A gateway between the building energy monitoring and control system (EMCS) and the Internet. This gateway is intended to present a common interface to the remote building monitoring control system via the Common Object Request Broker Architecture (CORBA) protocols.

Development of applications-level object specifications for HVAC objects, e.g., chillers.

A remote building monitoring and control center (RBMCC) which will provide data visualization, database management, building energy simulation, and energy usage analysis tools.

Deployment and testing of the system at Soda Hall, University of California Berkeley.

Control functionality is being deferred to Phase II. The initial applications will be data visualization and regression analysis of power usage of the chiller/cooling tower systems.

OVERVIEW

This paper is comprised of the following sections: Background, What, Why, How, Related Work, Design Issues, and Acknowledgements.

BACKGROUND

Buildings consume one-third of all energy in the United States at a cost of $200 billion per year, with $85 billion per year for commercial buildings. A large amount, perhaps half of this energy is wasted compared to what is cost-effectively achievable. Much of this waste is related to our inability to optimally control and maintain today's complex building systems. Recent building performance case studies suggest that typical savings of about 15%, and as much as 40% of annual energy use can be gained by compiling, analyzing, and acting upon energy end-use data (Herzog and Wheeler 1992; Claridge et al. 1994).

The applications under development for the Remote Building Monitoring and Operations (RBMO) project are based on utilizing existing capabilities of, and expanding upon information available through Energy Management Control Systems (EMCSs). Several studies have explored EMCS monitoring capabilities (Heinemeier, Akbari, and Tseng). EMCSs for commercial buildings are readily available. There are over 150 EMCS manufacturers (EUN 1994). About 50% of all buildings over 45,000 meter2 (500,000 sq. ft.) have an EMCS, and they are present in nearly all large offices (EIA 1992). For buildings built since 1992, almost 50% of the floor area is in buildings with EMCSs.

Today's EMCS have been built primarily for control. EMCSs are special-purpose computerized control systems, programmed to operate building equipment such as chillers, fans, pumps, dampers, valves, motors, and lighting systems. EMCSs are installed for many different purposes such as: controlling equipment, alerting operators to possible equipment malfunction, maintaining comfortable conditions, and permitting modification of control specifications.

EMCSs typically monitor building operational data such as damper positions, set points, state variables of the working fluids, and equipment status. They are not generally used to monitor electrical demand. In some cases, more accurate sensors may be needed for diagnostics than are typically included in an EMCS. For example, to track chiller efficiency, a very accurate measurement of the temperature drop across and water flow rate through the chiller is needed. The sensors in a typical EMCS may not be sufficient for this calculation. We have added additional flow sensors and better temperature sensors to the cooling plant at Soda Hall where we are conducting our research.

ASHRAE has, after a nine year effort, recently approved a new communications standard, for building automation systems—The Building Automation and Control Network (BACnet) Standard. This standard views the HVAC (Heating, Ventilating and Air Conditioning) system as a collection of objects. However, the standard does not (yet) include standard applications-level objects such as chillers or cooling towers. This project addresses the definition of such objects. We expect that BACnet will shortly be used to connect building gateways to EMCSs.

WHAT

Functionality

This project is developing software systems to support remote monitoring and control of multiple buildings, i.e., HVAC, lighting, etc., across the Internet, using CORBA (Common Object Request Broker Architecture) protocols. It is intended to work with heterogeneous EMCS and HVAC systems.

The ultimate users of the system will be owner/operators of multiple buildings: U.S. General Services Administration, school districts, universities, retail chains, banks, property management firms, ESCOs, utilities, et al.

Research Project Goals

The research project has two primary goals: demonstration of technical feasibility of the proposed design, and demonstration of the utility of the system.

Demonstration of the technical feasibility of remote monitoring is scheduled for fiscal year 1996, remote control in fiscal year 1997. A single EMCS is slated for fiscal year 1996, with additional EMCS's in fiscal years 1997 and 1998. Remote model-based control is slated for fiscal year 1998. Note that fiscal year 1996 ends Sept. 31, 1996.

Demonstrations of utility (improved energy efficiency) include statistical analysis in fiscal year 1996, simulation in fiscal year 1997, and model-based control in fiscal year 1998.

WHY

Close attention and careful analysis of the data from building EMCS's typically affords many opportunities to improve building operations, resulting in improvements to occupant comfort and reductions in energy use.

However, for most buildings such close attention and analysis are not undertaken, due to lack of appropriate software, operator training, staff, or inaccurate or malfunctioning sensors. Remote building monitoring offers the possibility to reduce the labor costs involved in monitoring/analyzing EMCS's by spreading such labor costs over a large number of buildings. This will also make it economically feasible to employ expert HVAC engineers.

Use of the Internet has two aspects: use of the Internet communications protocols, and use of the actual Internet network.

Use of Internet networking protocols permits access to a wide variety of affordable interoperable hardware and software from many different vendors over many different media. Internet markets are huge, in the millions of users, hence vendors can readily amortize development costs. In contrast, proprietary protocols typically entail more expense, because of lack of competition and because development costs are being amortized over smaller markets. Industry specific protocols, such as BACnet, fall in between these two extremes. Internet protocols are clearly the most popular for wide area networking applications.

Use of the Internet network permits users to share the costs of a common communications infrastructure.

When building automation applications can share existing Internet infrastructure, substantial savings over telephone dial-up systems are possible (Haberl 1996). The Internet also offers the prospect of inexpensive access to high bandwidths when needed -e.g., for remote video surveillance for security, fire, or remote diagnostics. Finally, the Internet offers a reliable, redundantly connected, backbone. The downside of using the Internet is the necessity of more stringent security precautions, discussed further below.

HOW

In this section we briefly describe the following components of the project:

- Gateway systems in each building
- Applications-level object specifications

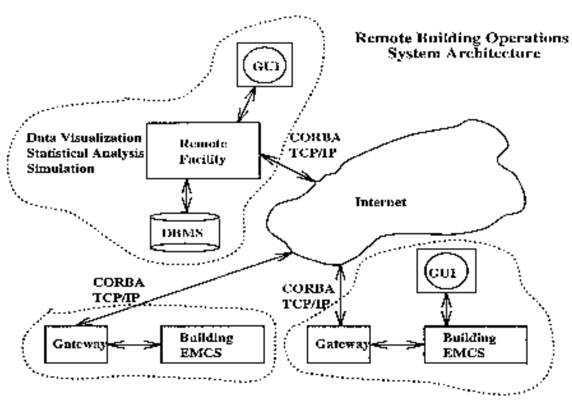
- Remote monitoring and control facility
- Prototype deployment and testing

More detailed discussion of design issues follows in a later section.

Each building will have a building gateway system to interface between the building energy monitoring and control system (EMCS) and the Internet. This gateway is intended to mask the heterogeneous EMCS and HVAC systems by presenting a common interface to the remote building monitoring control system via the Common Object Request Broker Architecture (CORBA) protocol (discussed further below).

One such gateway system will be installed in each building. Ultimately, we would expect that EMCS vendors would incorporate thi software into the EMCS. The gateway systems will be built using the Windows NT operating system, running on PC's (See Figure 1.)

Figure 1. *System Architecture*



Notes: GUI = Graphical User Interface

We are developing applications-level object specifications, written in the CORBA Interface Definition Language (IDL), for HVAC objects, e.g., chillers, for use in the gateway protocol. These specifications are strongly influenced by the work of the Industry Alliance for Interoperability on developing a common data model to describe buildings. This is described further below.

We are also developing a remote building monitoring and control center (RBMCC) which will (ultimately) provide data visualization, database management, building energy simulation, and energy usage analysis tools. The remote monitoring facility will be comprised of two components:

- A data acquisition and database management server which will be built on a Unix system.
- Several PC-based analysis workstations, which will be used for data visualization, statistical analysis of the data, and simulation.

A prototype system is under development for a case-study site on the U.C. Berkeley campus. Soda Hall is a 10,000 meter[2] (109,000 sq. ft.) building on the U.C. Berkeley Campus. It houses students, faculty, and a host of computers as the home of the Electrical Engineering and Computer Science Department.

The building was constructed in 1993 and fully occupied in 1994. The cooling plant contains two 220 ton screw chillers on a primary loop that maintains constant flow through the chillers. The secondary loop has variable frequency drives to allow the chilled water flow to be matched to the cooling loads called for at the cooling coils. Two two-speed cooling towers provide condenser water to the chiller and additional cooling units distributed through the building's interior computer centers.

Soda Hall has been the focus of another LBNL research project to evaluate information transfer through the entire building life cycle, and the use of tools to improve overall building performance.

Soda Hall was chosen because of our familiarity with it, its proximity, Internet access, and because of the cooperation of the facilities management staff, occupants and control system vendor.

APPLICATIONS SOFTWARE

The RBMO applications are designed around providing the following three capabilities:

- Archiving historical data in a database
- Providing standard graphics for performance analysis
- Performing a series of regressions and statistical analysis techniques to (1) define ''baseline'' conditions and (2) evaluate energy performance after a retrofit, operations and maintenance changes, occupancy changes, or for historical tracking.

We envision that applications software—statistical analysis, visualization, simulation—will run primarily in the PC-based analysis workstations, running Windows NT. This approach was chosen to permit use of applications software developed for the Windows and Windows NT operating systems.

Initial applications will focus on the use of standard regression models to model energy usage as a function of weather. Such regression can be used to estimate the energy savings produced by retrofits, in the presence of confounding changes in weather. We are initially concerned with the energy usage of the cooling plant.

The whole-building and cooling plant monitoring at Soda Hall consists of a few dozen sensor points (out of 1500 total sensor points in the building) that cover whole-building electricity use, weather variables, plus chiller power and cooling tower status, and several temperatures and water flow rates. We added several power and flow meters, and temperature sensors to the cooling plant to compare them with the original EMCS sensors and augment information that was not available from the EMCS.

We are developing a standard set of performance tracking plots to allow users to view archived data with a user-friendly menu. This will include daily (24-hour) load shapes of 5-minute operating data for all values; weekday, weekend, and weekly load shapes (hourly data); and monthly average load shapes. The chiller and cooling plant analysis will consist of plots such as power versus cooling load (kW versus tons) and efficiency versus load (kW/ton versus tons).

The applications are intended for use by an remote expert. Most of the focus on the graphics is on energy use. However, the capability will exist for the user to look at detailed data such as time series of cooling plant water temperatures or cooling tower fan start-stop intervals.

The concept is to provide a tool for a remote user who might be responsible for tracking the performance of building systems at multiple locations. The menu of standard graphs are designed to allow the user to easily view the most critical, marco-level performance data, while providing additional means for more detailed analysis of micro-level data. In other words, the scripted graphs should allow the user to answer the question, ‘‘is the building and cooling plant operating well?’’

The applications will also include a regression model tool known as EMODEL (Kissock et al. 1994). The purpose of the model is to allow one to evaluate the energy savings from an intervention, such as a change in the control set points or a retrofit. EMODEL is a tool for building energy use data, with single, multiple, and linear regression algorithms, including change-point and bin analysis. Four-point change-point models are useful when there is simultaneous heating and cooling in a commercial building (Ruch & Claridge 1992).

In fiscal year 1997 we plan to integrate some control capabilities into the system. This will require the availability of a secure version of CORBA, not yet readily available. We also plan to integrate HVAC simulation tools, such as SPARK, into the analysis.

In FY 98 we plan to integrate model-based control into the system.

RELATED WORK

Remote Monitoring

A number of related R & D projects are underway: Electro-Tek, Texas A & M, Ryerson Polytechnic, RPM Associates, EDS.

These project vary in their purposes, communications technologies, building interfaces, database management systems, etc.

ElectroTek Corp. has a research project (Electrotek 1996) focused primarily on remote monitoring over the Internet of electric power quality and usage. It employs a data acquisition/database server running a relational database, connected to gateway machines via TCP/IP over the Internet. The gateway communicates using the newly developed Power Quality Data Interchange Format (PQDIF). The gateway machines in turn use broadband communications to monitoring devices within the building, either to circuit monitoring equipment or another PC interfaced to additional power quality monitoring instruments. PC’s running Windows NT are used for all of these machines about both the building and remote sites.

The Texas A & M system (Haberl 1996) provides for remote monitoring over the Internet of data loggers recording electric energy usage at various buildings on the campus and elsewhere. They use printer control protocols over TCP/IP. Printer controllers are then used to interface data loggers to Internet. This approach is quite inexpensive. A relational DBMS is used. Statistical analysis is done with SAS and custom analysis software. Security is provided via IP address filtering—which can be defeated by address spoofing. The remote data acquisition and database server runs on a Unix server.

Ryerson Polytechnic has developed a Unix-based remote monitoring system, Axon, (Ott 1996) for Bell Canada. The goal of the system was to provide a common user interface for a number of different EMCS systems, to reduce training costs. The system talks to 18 different types of EMCS systems over serial lines using the proprietary protocols of the EMCS vendors. The system has a centralized data acquisition and database server and supports multiple remote front ends (user interface machines) communicating via UDP.

RPM Associates has developed a system (Lake 1996a; Lake 1996b) for remote power quality monitoring which uses SNMP (Simple Network Mgt. Protocol) (Cohen 1995; Rose 1995)

RMON (Remote Monitoring Protocol) over UDP/IP. It can be used across LANs or the Internet.

EDS (Electronic Data Systems) is exploring the development of remote environmental and power monitoring systems for Federal Avition Administration (FAA) facilities based on SNMP (akin to RPM Associates).

Aready commercial remote building monitoring systems are available. Typically, these employ the EMCS vendor's proprietary protocol to speak to each EMCS. Dial-up telephone lines are typically used for communications. An example is the Measuring and Monitoring Services, Inc. system which uses dial-up phone communications between a central PC-based data acquisition system and data loggers in various buildings to collect lighting system usage and power usage data (Bowman 1996).

Building Life-Cycle Information System (BLISS)

The remote monitoring project will be integrated into the systems being developed as part of a larger effort at LBNL to develop tools to improve the transfer and usefulness of building performance data throughout the building life cycle. A tremendous amount of information and knowledge is lost as buildings move from design to commissioning and operations. This loss results in buildings that are not operated, controlled, or maintained as intended. We are examining problems associated with current building information transfer methods and preliminary designs for Building Life-cycle Information Systems (BLISS). The remote monitoring tools that are the primary subject of this paper are a crucial part of the proposed life-cycle information systems. They are needed to compile the time-series data for ongoing performance tracking and evaluation. See (Selkowitz, et al. 1995) and (Mills 1995) for overviews of the BLISS project. See (Piette, 1996) for a discussion of building commissioning aspects of BLISS.

Industry Alliance for Interoperability (IAI)

The Industry Alliance for Interoperability (IAI 1996) is a consortium of architectural / engineering / construction (AEC) software vendors (e.g., Autodesk and Bentley Systems) who are working on developing a standard data model for description of buildings. The data model is intended to be used by architectural and engineering design tools, construction cost estimation software, construction scheduling software, etc.

The IAI data model is now being written in EXPRESS, the modeling language adopted by the STEP/PDES product data interchange standards community. IAI and STEP are attempting to coordinate their efforts.

Part of the IAI data model encompasses HVAC description. Our data modeling efforts, while more limited than IAI, give careful consideration to compatibility with the IAI model.

DESIGN ISSUES

The central design issues to be confronted in building a remote building monitoring and control system are:

- Choice of distributed computing environment—CORBA vs. OLE vs. SNMP DBMS selection
- When to transpose data
- When to bind the database schema
- How to perform applications integration and interface to DBMS
- Construction of common abstraction of multiple EMCS and HVAC Systems

OLE vs. CORBA

The distributed (a.k.a. networked) version of Microsoft's OLE (Object Linking and Embedding) software is the principal competitor to CORBA (Common Object Request Broker Architecture) as a general purpose object-oriented distributed computing environment. See Table 1 for a summary of the differences between the two systems.

CORBA offers two critical advantages for our project. It is readily available now, whereas distributed OLE is not. (Note that the single system version of OLE is widely used.)

Secondly, the CORBA object is fairly standard and supports multiple inheritance, whereas OLE does not support even single inheritance. Inheritance permits one to specify that centrifugal chillers are a subtype of chiller and hence inherit all of the properties (and operations) of generic chillers. This permit much more concise descriptions of object classes. Multiple inheritance permits an object class, such as automobile, to inherit properties (and operations) of multiple parent classes, e.g., motor vehicles (engine size, number of cylinders) and wheeled vehicles (number of axles, number of wheels, wheel diameters). Multiple inheritance permits fur-

Table 1. *Comparison of OLE and CORBA*

Feature	OLE	CORBA
Vendors	Microsoft	SUN, HP, DEC,IBM, Iona, Expersoft, et al.
Interoperability	Moot	Now
Operating Systems	Windows, NT	Unix, Windows, NT, QNX, VX-works, et al.
Distributed Version	Promised soon	Now
Object Model	Lack inheritance Incompatible with IFC	Multiple inheritance Compatible with IFC
Standards Org.	Microsoft	Object Management Corp.
Desktop Presence	Strong	Weak
Compound Docs	OLE	OpenDoc
Security	Unknown	Standard promised, some now
Languages	C++, C, Visual Basic	C++, C, Smalltalk, Java
Event services	Yes	Yes
Scalable	Unknown	Yes
Performance	Poor in alpha	Varies
Communications	Synchronous Remote Procedure Call	Synchronous Remote Procedure Call
Multi-threaded	Unknown	Most implementations

ther economies in class specifications. Note that multiple inheritance of CORBA meshes well with similar facilities in the programming language C++ and most object-oriented DBMSs. Also, the IAI data model, known as IFC (Industrial Foundation Classes) employs multiple inheritance. Thus CORBA is more compatible with the IFC than OLE.

See (Orfali, Harkey & Edwards 1996) for an extensive comparison of CORBA and OLE. Also see (Ben-Natan 1995) and (Mowbray & Zahavi 1995) for detailed discussions of CORBA. See also the Object Management Group's web page (OMG 1996).

OLE, CORBA Coexistence

Gateways exist between CORBA and OLE from several vendors. These gateways will generate OLE Automation Interface from CORBA IDL (Interface Definition Language). Note that the CORBA IDL can be used for interface definition in either single machine or distributed setting, i.e., the use of CORBA IDL does not dictate the partitioning of programs the among machines.

CORBA vs. SNMP

SNMP is the Simple Network Management Protocol, developed by the IETF (Internet Engineering Task Force) for use in Internet based networks for network management. It typically uses the connectionless UDP/IP datagram protocol rather than the connection-based TCP/IP. There is wide vendor support for network devices. It is object oriented, however the protocol only allows set/read individual objects vs. invocation of arbitrary object operations. Hence, this simple protocol will likely require substantially more network messages than CORBA to accomplish similar operations. CORBA permits one to define object operations which involve reading and/or setting multiple object parameters. Thus, in principle CORBA should offer better performance.

There is (as yet) little use outside of network management, although we are beginning to see its use for power monitoring, especially in uninterruptible power system (UPS) environments. It uses the ISO protocol ASN.1 for data exchange. The C programming language is the preferred embedding. SNMP Version 2 includes security mechanisms for both authentication and encryption. See (Rose 1994) for a more detailed discussion of SNMP.

CORBA is typically used atop TCP/IP protocol. C++ is the preferred embedding. There is broad (500) vendor support. It is applicable across many types of distributed applications. It primarily offers synchronous RPC (remote procedure call) across heterogeneous platforms. There are some asynchronous event services (messages). It uses the new IIOP protocol (atop TCP/IP) for interoperability/data exchange. It allows arbitrary object operations. It allows ''brokering of requests'' - clients need not know the location of the server they require—the broker will find it and if necessary activate the server. There is no security as yet—the Object Management Group (OMG) is working on the standard.

It should be possible to construct gateways between CORBA Systems and SNMP systems. Note that CORBA functionality largely subsumes SNMP functionality (except (as yet) for security).

CORBA vs. DDE

DDE is the Dynamic Data Exchange protocol defined by Microsoft Corp. in the mid to late 1980's. This protocol was originally used within a single processor. Subsequently Wonderware and Microsoft introduced networked versions of DDE which ran atop TCP/IP. The protocol uses ASCII (i.e., text) encoding to pass command strings (and arguments) to programs It is not object-oriented. The syntax and semantics are entirely defined by the applications. Each application must parse the incoming command strings. Hence, it has a reputation for being slow. Microsoft has obsoleted it with the development of the OLE protocol.

The attraction of the networked DDE protocol is the wide availability of support for DDE among commercial software vendors, especially those in industrial control systems. CORBA offers a much richer object model and object services, whereas DDE only offers only transmission of uninterpreted strings. CORBA's use of binary encodings leads to better performance. CORBA Interface Definition Language can be used to specific object operators, largely avoiding the need for parsing command strings.

DBMS Selection Criteria

The bulk of the data we are collecting will be time series, e.g., of temperatures, power usage, etc. Although the raw data may be irregular time series, we will transform these to regular time series for analysis. Regular time series assume periodic temporal sampling. Hence, our most important criterion for selection of the database management system (DBMS) is its suitability for time series data and queries.

It is possible to support time series data on any of several DBMS: relational, object-oriented (OO), or hybrid object-relational. Use of relational DBMS for regular time-series data, typically offers mediocre performance, weak support for operations such as smoothing and calendars. Object-oriented DBMSs permit the implementation of time-series data collections with better support for calendars, smoothing, etc. However, no commercial object-oriented DBMS yet provides off-the-shelf support for time series data, so the user must code his own. In contrast, one of the hybrid object-relational DBMSs, Illustra (Illustra 1996), offers built-in time-series support.

Most of the data which are not time series are building description data—i.e., CAD (Computer Aided Design) data describing the physical configuration of the building, HVAC system, and the EMCS system. Object-oriented DBMSs (OODBMSs) are generally much better suited to CAD data than relational DBMs (RDBMSs), both because the object data model is more closely matched to CAD data modeling requirements, and because OODBMSs typically offer much better performance for CAD applications. Indeed, CAD applications were the primary drivers for the development of OODBMSs.

Ideally, we would like to use a single DBMS for all BLISS activities, including the building monitoring data. Particularly during the design phase of the building, the CAD data management will require extensive support for versioning of the design data, and support for long transactions (so-called check-in/check-out) to support design activities.

Other criteria for selection of the DBMS include facilities for integration with popular statistics packages. Usually, this is available for the major relational DBMSs, but not object-oriented DBMSs. CORBA interfaces, for at least some of the commercial CORBA implementations, are available for several object-oriented DBMS, but not typically for the relational or hybrid DBMSs.

Support for client-server DBMS configurations is typically available for all of the DBMSs. This will allow us to move the analysis and visualization codes to the PC-workstations while maintaining the database on a robust database server.

The ability to support distributed data management, i.e., querying across multiple database servers, and support for updates across multiple database servers are also important for the design phases of BLISS. It is expected that, for large commercial buildings, there will be multiple designers (architects, structural engineers, mechanical engineers, et al.) at diverse sites, each with their own building representation, who will need to work together.

Data Transposition

Our telemetry data on the building state are initially available as cross-sectional data, i.e., we sample the entire building state periodically, typically at 1-5 minute intervals. However, typical analyses use only a few state variables, but will typically want to look at long time-series of each such state variable. Thus it is expedient for analysis purposes to have the stored data in a separate time-series for each state variable.

The question then arises as to when and where the data are to be transposed from cross-sectional to time-series storage formats. This can be done at collection time, analysis time, or some intermediate time.

Transposition at collection time slows the collection process, but speeds the analysis phase. Transposition at analysis time permits very fast data collection, but slows the analysis phase.

Transposition at intermediate times permits both very fast data collection and fast analysis. However, the software architecture becomes more complex and costly to implement and maintain.

Transposition can also occur either at the gateway machines, the database server, or the analysis workstations.

We have chosen to transpose the data at the database server as it is collected. This will generate at least one disk I/O operation per data point monitored for each sampling period. Our rationale for this choice is that this appears to be the simplest architecture to implement, and should have adequate performance for our prototype system. If we were to scale our system to much larger collections of buildings we would perhaps need to adopt a scheme of intermediate time transposition.

Schema Binding Time

Another major design issue is when and how tightly to bind the user's database schema (i.e., database design) to the database schema used by the database management system. This is analogous to an architect deciding whether to incorporate the current office layout as either structural or non-structural walls, modular walls, or cubicles. The schema binding time decision involves tradeoffs among the performance of the system, difficulty in implementing the system, and the flexibility in adapting the system to changes in the building design or EMCS configuration.

Note that we distinguish here between the user's DB schema, and the schema employed by the DBMS. These need not be (and often are not) the same. In EMCS parlance the user's schema is often referred to as the naming convention for sensor points.

Alternatives include:

- a fixed compile-time complete binding of the user's schema into the DB schema,
- a completely dynamic run-time binding of the user's schema into a generic DB schema
- binding of the user's schema at system initialization time.

Compile-time binding involves direct binding of the user's objects and attributes in the database schema and code. Here the user's schema and the DB schema are virtually identical. The advantages of this approach include fast performance, simple architecture and implementation. The disadvantage is that it is difficult to modify, and may require the system developer to supply the user with source code for the system.

The dynamic schema binding approach entails the use of a very generic DB schema, to which the user's schema is bound at run-time. Thus the DB schema might consist of a basically single table, with fields for object name, attribute name, attribute value, and timestamp. The user's schema thus becomes data in the generic DB schema. This approach offers enormous flexibility, standard DB schema and code at all sites. However, this is often at the expense of performance penalties.

Furthermore, such designs often ignores the type system of the underlying DBMS, requiring that all attributes be stored as text strings.

Another common strategy, particularly in data acquisition and control systems, is to bind the user's schema to the database schema at system initialization time. The advantages are good performance, and reasonable flexibility. The disadvantages are more complex design than compile-time binding, and less flexibility than dynamic binding.

Gateway System

In each building, a gateway system will mediate between the EMCS and the remote monitoring and control system (via the Internet). It will interface to the local EMCS via proprietary protocols (or possibly BACnet). Typical EMCSs are hierarchical control systems comprised of a host processor, which support the user interface, and several control processors on a local area network, which run local control loops and interface to several multiplexors each. We would prefer to connect our gateway machine to the host processor, in order to minimize potential conflicts arising from concurrent access to the control processors by the gateway and host processors, and to obtain building data in meaningful engineering units. However, in the case of Soda Hall, we concluded that interfacing to the control processors would be the most expedient solution, due to ongoing system configuration changes to the EMCS host processor.

A gateway testbed facility has been created which includes a small version of the EMCS system. This testbed permits us to develop and test our gateway software without affecting building operations at Soda Hall.

Control and Security

At present we do not yet support control functions, for two reasons:

(1) lack of a secure CORBA implementation,

(2) lack of concurrency control in the building EMCS.

Remote control of buildings across the Internet exposes the gateway systems to attack from anywhere on the Internet. Systems which employ private communications networks (leased lines) are less exposed to such attacks. Systems which employ other public networks (dial-up telephone systems) have similar security problems.

Hence, secure CORBA implementations will be required. Our primary concern is authentication and authorization at the gateway machine of remote operators/controllers across the Internet. We assume a secure (e.g., physically secure) communications channel between the gateway system and the building EMCS. We are not concerned in this project with intra-EMCS security, e.g., issues arising from sharing local area networks with other users.

Present commercial CORBA implementations lack both authentication and privacy (i.e., encryption) capabilities. OMG has recently adopted a draft security services specification, which has yet to be implemented. We know of at least two projects which are attempting to build secure CORBA ORBs based on commercially available ORBs (i.e., Iona's Orbix), the Sunrise Project at Los Alamos National Laboratory, and another project at Sandia National Labs in Livermore. We expect to avail ourselves of a secure CORBA implementation in the second year of the project. Note that both encryption and public key-based digital signatures for authentication are commercially available technologies. The issue is primarily one of system integration.

The other obstacle to supporting control functions, concerns concurrency control at the building EMCS, i.e., coordination of multiple operators/computers independently attempting to control the same HVAC equipment. Legacy EMCSs (e.g., our target system) often support either only a single operator control console, or require manual intervention for concurrency control. Remote operator controls further complicate such manual intervention.

CONCLUSIONS

In this paper we have described our project to construct a remote building monitoring and control system, which will employ the CORBA protocol across the Internet for communications.

We have discussed related work, tradeoffs between alternative networking/distributed object protocols, tradeoffs among various CORBA and DBMS systems, and a number of design issues in constructing such systems.

We have also outlined the monitoring applications we plan to support in the first year.

We believe that this approach will prove to be both feasible and competitive with other systems based on proprietary communications protocols.

A secure CORBA implementation will be needed to support remote control functionality. Retrofitting concurrency control mechanisms into legacy EMCS systems will also be required.

The attraction of our approach lies in the extensive availability of commercial software products which support distributed computing applications based on the CORBA model and underlying Internet communications protocols.

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