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Machine to Machine Communication for Smart Systems using MQTT

Ullas B S[1], Anush S[1], Roopa J[2], Govinda Raju M[2]

8th Semester students, Dept. of Electronics and Communication, R.V.College of Engineering, Bangalore, India[1]

Assistant Professor,Dept. of Electronics and Communication, R.V.College of Engineering, Bangalore, India[2]

ABSTRACT—With increasing appliances at home and industries, the necessity to accommodate hundreds and thousands of sensors for successful automation is of great prominence in the field of M2M communication. HTTP protocol was well known for remote monitoring, analysis of data from large number of sensing elements. Systems using HTTP consumed more power, had lesser efficiency of transmission and could not utilize system bandwidth efficiently [1]. The protocols MQTT, AMQP and CoAP, capable of handling sensor traffic under low bandwidth and constrained network conditions are extensively used to improve automated systems [2]. In this paper , a smart system implemented using MQTT Client protocol for industrial and home automation applications has been proposed to solve above mentioned problem. The proposed smart system uses a microcontroller platform for the implementation of MQTT Client, a IEEE 802.3 standard Ethernet connectivity shield for internet publishing and set of sensors for obtaining real time data.

INDEX TERMS—Machine to machine communication, IoT, MQTT

I. INTRODUCTION

With the ongoing development of the social economy [3], a large number of home appliances and industrial appliances have been presented into our day to day lives. While, people pursue ever-growing high quality of life, this leads to more and more facilities and home appliances poured into their buildings. Recent years have witnessed the emergence of machine-to-machine (M2M) networks as an efficient means for providing automated communications among distributed devices [4]. The ideas of smart home and smart industry are gaining importance in the present context due to their ability to automate industrial and home environments with great effectiveness. Smart systems are defined as miniaturized devices that incorporate functions of sensing, actuation and control. They are capable of describing and analyzing a situation, and taking decisions based on the available data in a predictive or adaptive manner, thereby performing smart actions. The control of such appliances and devices at home or industrial work environment is a complex matter due to two important reasons. Firstly, the control expected out of such automation applications is far more compact compared to the control provided by traditional control systems. Secondly, in such applications there is always the human element that comes to force, wherein the people accommodating the homes or working in the industries expects to occupy a comfortable, healthy, secure, economy and convenient space. Home networking is the core to the implementation of an automation system for a smart home.

Traditional home networking systems are implemented on wired platforms like CAN, UART etc. A wireless approach can replace wire harnesses within home network sensing and control system applications. Use of a dedicated messaging protocol is very suitable for controlling ever increasing facilities and appliances in a house. To figure out a solution, a smart system for a home implemented using MQTT Client has been proposed in this paper. The smart system uses the technologies of Internet of Things (IoT) which adopts sensors, Ethernet communication and actuator network running application specific algorithms. The MQTT Client board capable of performing publish and subscribe operations is the core part of the proposed idea. Depending upon the type of facility required and the appliance to be controlled in home or industrial environment the choice of microcontrollers i.e., independent microcontrollers or single powerful microcontrollers can be done. The smart system is capable of being monitored from remote locations through the use of utility tools for MQTT protocol and also helps in remote control in case of emergencies. The development of a low-cost electronic prototype, which is designed for monitoring and controlling home appliances via Remote Client, has also been discussed [5].

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The rest of the paper is organized as follows: Section II deals with home automation system block diagram. Section III deals with basic concepts on MQTT Protocol and messaging middleware. Section IV of the paper deals with the design and development of smart system based on ideas of IoT with the help of MQTT protocol. It also provides a brief description of the criterion for the choice of hardware elements and software platforms for the development of the home or industrial automation application using MQTT protocol. Section V depicts the results of sensor data publishing and subscription with the help of a graphical user interface developed on java platform. Section VI concludes the paper and provides idea regarding future scope and work.

II. SYSTEM BLOCK DIAGRAM

Figure 1 of the paper depicts the block diagram of the home automation system using MQTT. The block diagram shows the scenario of two or more locations of an industry/house being fitted with sensors. Every "Location" consists of an Atmega 328 microcontroller with additional application specific peripherals along with an Ethernet shield which is used to connect to the internet and publish data on to the Server/Broker. The MQTT client is implemented on the Atmega 328 microcontroller. The Atmega 328 microcontroller at each location is programmed to publish data onto the Server/Broker. The data from the sensors are published to the Server/Broker under unique topics. Additional devices like LCD, GSM are used to improve user interface. The block diagram also depicts the use of a remote client such as a tablet, PC, application boards. These remote clients subscribe to a specific topic on the Server to access information being published on the topic and are an integral part of remote monitoring applications. The centralized control used in the block diagram is another microcontroller implementing algorithms and performing actuation.

III. MQTT PROTOCOL AND MESSAGING MIDDLEWARE

The integral part of the home automation implementation is the MQTT client. The MQTT client is implemented on the Atmega 328 microcontroller as a software code. Some basic concepts on MQTT and messaging middleware is as follows

A. Middleware

Middleware is defined as the software which provides a messaging fabric to link applications and systems together. The alternative to not using a middleware system is that the application writer has to deal with the mechanics of getting messages from A to B, dealing with connection failures, network outages, duplicate messages etc [6]. The use of middleware helps the application writer to communicate messages from one system to another system in remote locations. The IBM Web sphere MQ is one such messaging middleware that allows collaborating applications to intercommunicate via a central hub, known as a Message Broker.

Therefore data producers can produce desired set of data and just set up a MQTT publish to the Broker. On the other hand a Subscriber can subscribe to the published topic and extract data for actuation or remote monitoring.

B. MQTT

MQTT (MQ Telemetry Transport) is one of the protocols supported by the IBM Message Broker products as a communicating data to and from the Broker [7]. The protocol was designed specifically for remote telemetry applications, with three specific design goals: (1) It should offer a once-and-once-only assured delivery mode to enable a message to be reliably transferred all the way from a remote sensor to a back-end application.(2) The protocol should be as lightweight as possible across the "wire" (or other communication medium) most remote telemetry is done over low bandwidth, high cost networks, and so minimizing the overhead of each message is highly desirable. (3) The protocol should be very easy to implement on embedded devices such as sensors and gateways.

C. BROKERS

Many industry initiatives have been integral in the development of MQTT and its applications in Internet Of Things. Companies like IBM, Eclipse and forums like OASIS have been integral in resource development for MQTT and its prototyping for practical applications. Various Broker or servers have been developed and released for Public Domain usage for application development on MQTT. Some of the projects are PAHO, MOSQUITTO by Eclipse, messaging middleware like Web Sphere MQ and servers like m2m.eclipse.org and test.mosquitto.org have gained huge fame and

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have been used by developers since their creation. Web Sphere Business Integration Message Broker (WBIMB), Web Sphere Business Integration Event Broker (WBIEB), and Web Sphere Connection Server Micro Edition (WCSME) are also a few small and big sized brokers for small scale and industrial scale applications.

IV. A SMART SYSTEM BASED ON IOT USING MQTT PROTOCOL

The smart system proposed in the paper is based on IoT technologies and consists of three important parts: MQTT Client Publisher, Server or Broker and MQTT Client Subscriber. The overall system is depicted as shown in Figure 1. The MQTT Client Publisher is a microcontroller with MQTT protocol implemented in Publish mode using Embedded C or any microcontroller based software platform. The Publisher is capable to extracting sensor data from single or multiple sources and publishing it through topics on to a server hosted as part of public domain or private secure servers. Private servers offer a better security guarantee than public hosted servers. Server is a storage and computationally equipped hardware with support software. For the publisher to be able to communicate with the server efficiently a Broker MQTT must be implemented on the server with the communication port specified to the Publisher. The MQTT Client Subscriber is device with MQTT Client implemented in Subscribe mode. The Subscriber is capable of accessing the data on the server through a subscription to particular topic.

The proposed paper provides basic implementation of the following three systems used in home automation applications: Firstly, a smart temperatures control system, Secondly, a smart metering system and lastly a smart home patient health monitoring system.

A. SMART TEMPERATURE CONTROL

Home and industrial environment temperature control are key areas of work and research in the present day. Improvements to existing systems and integration of newer technologies to existing systems are continuously being worked upon. The above mentioned system uses a temperature sensor DS18B20 by Dallas Semiconductor for temperature measurement. The key blocks in the sensor data acquisition are: ADC, Signal conditioning and interpolation logic. The ADC deals with analog to digital signal conversion with required amount of precision and resolution. The signal conditioning is required to boost up analog signal strength to suitable levels so as to ensure good signal interpretation and data conversion.

The temperature data from the Publisher is observed in the broker or the server under the specified topic name "/temperature/" temporarily. The Subscriber subscribes from the remote location to the server on the desired topic to extract the data. Based on the temperature data obtained real time remote temperature monitoring is done, also the Subscriber sends commands to local controllers for actuation of room heaters and air conditioners. The Subscriber itself actuates devices for smart temperature control based on its access to central actuation system.

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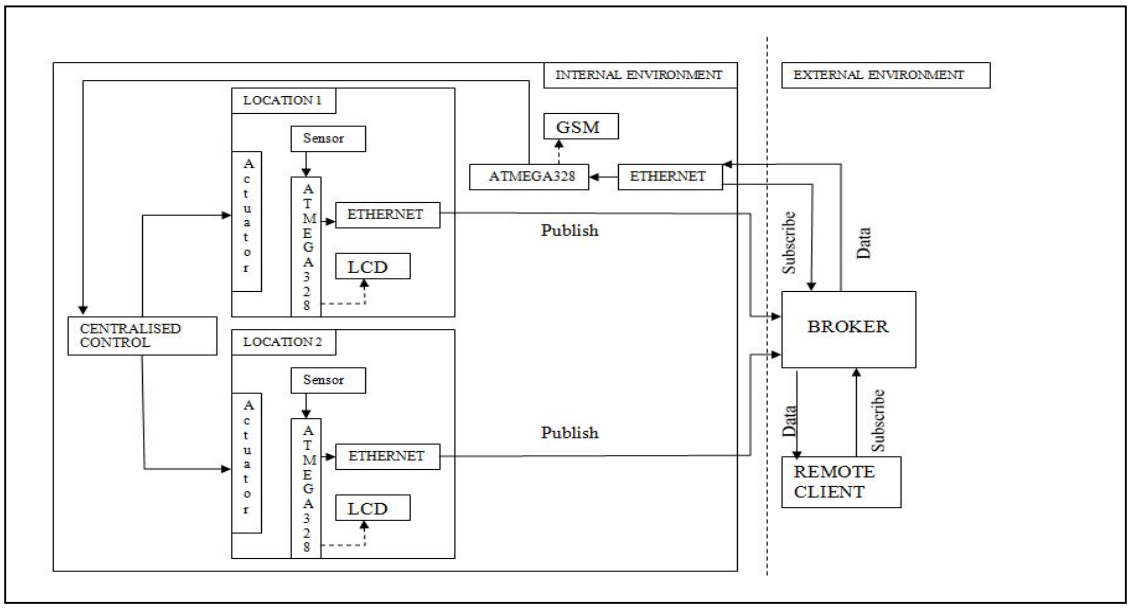

Fig. 1. Block diagram of the system

B. SMART METERING SYSTEM

Traditional water billing and control systems are based on water consumption data collected by technician. A smart meter is an electronic device that records consumption of water in intervals of an hour or less and communicates the information daily back to the utility for monitoring and billing purposes. Such an advanced metering infrastructure differs from traditional automatic meter reading in that it enables two-way communications with the meter. Smart metering differs from advanced metering systems due to the fact that smart meters are capable of two way communication i.e., sensing from user and also actuation from the control end. The water supply board forms the control end of our application. There has been design and developments of smart meters predicting the usage of power consumption in earlier papers [8].

The proposed smart metering system comprises of two important parts: Firstly, the embedded front end comprising of flow sensor, LCD display and GPS integrated onto an embedded controller. Secondly, Software support at the water supply board for interpretation and actuation.

LCD

A 16*2 LCD is used at the user end to display the water consumption levels for user reference. The water consumption value serves as reference to the user for controlling the water flow locally at home to stay within budget constraints.

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FLOW SENSOR

The Smart metering mentioned above uses a flow sensor POW110D3B for flow rate measurement. The flow sensor consists of a Hall Effect sensor and a free moving valve setup to determine the flow rate of water. A Hall Effect sensor is a transducer that varies its output voltage in response to a magnetic field. Using this variation the flow rate of water can be determined.

GPS

GPS is used at the user meter to determine the location of the user. This location serves as an address for storage of water consumption data at the water supply board.

ACTUATION

The water supply board implements a embedded application with software support to compare the current water usage and predefined water usage values by the user. This forms a basis for prepaid water billing. Based on the comparison the water supply board actuates valves using servo motors in the proposed prototype. The control end is also equipped with GSM support for automatic bill generation and disposal.

The amount of water consumed from the Publisher is observed on the broker or the server under the specified topic name "/flow rate/" temporarily. The Subscriber subscribes from the remote location to the water board server on the desired topic to extract the data. Based on the consumption data obtained real time remote water consumption monitoring is done, also the Subscriber sends commands to local controllers for actuation of water valves to limit the flow of water to household or industry.

C. SMART HEALTH MONITORING SYSTEM

Home patient health monitoring has been a major concern among the working folk of the country. Mortality rates have risen due to inappropriate and inefficient monitoring of home patient health parameters. Newest technologies have been successful in using embedded solutions with GSM and GPS support to monitor danger posing situations to home patients. But these systems are not able to provide remote continuous monitoring of health parameters and avert danger to life before the inevitable [9]. With the evolution in technologies like IoT and protocols like MQTT the chances of achieving such a real time health monitoring system is very bright. Our proposed module is a prototype of the above mentioned system and is capable of providing remote monitoring and response initiation. The system uses highly efficient heart rate and temperature sensors for the measurement of vital body parameters. The data so obtained is published using a MQTT Client to a server.

Simple IR led and detector pair can be used for the detecting the heart rate from the tip of the finger. The signal from the IR detector can be conditioned using op amp signal conditioning circuit as shown in Figure 2. The signal conditioning circuit is specifically designed to boost up the analog signal strength from the IR detector. The conditioned signal can be used to for A/D conversion and interpretation. The data on the server can be subscribed and accessed by the hospital authorities for check up and analysis. This method of remote monitoring the patient's health condition is part of post hospital patient care and helps in prioritizing the visit of patients to hospitals. The proposed system also is capable of performing early diagnosis and also helps in critical patient follow up care.

V. RESULTS

This section of the paper deals with the results that encourage developers to use MQTT as a messaging protocol in their applications. The section provides comparative results for MQTT and HTTP for the fields transmission efficiency, delay and battery consumption.

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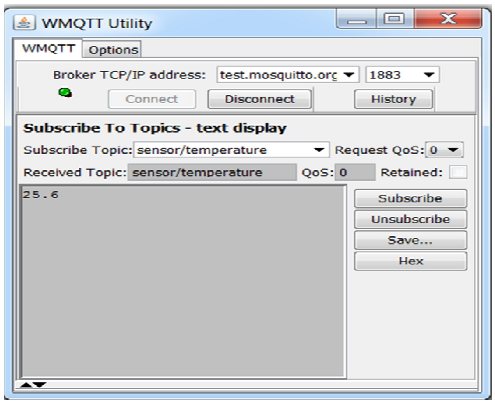

Fig. 2. Room temperature appearing in WMQTT Utility

WMQTT IA92 Java utility is part of a collection of Java implementations of MQTT client APIs provided by IBM. It provides a simple GUI allowing user to test publication and subscription with their broker. Figure 2 illustrates an Arduino-based device that publishes to a topic using the MQTT protocol. The device is a simple temperature sensor that measures the ambient temperature and publishes to the topic "sensor/temperature" on an MQTT server.

The MQTT client was implemented on Atmega 328 microcontroller using the embedded C language. The microcontroller was programmed to publish a fixed payload to the server at regular intervals. Out of 120 messages sent using MQTT client 117 messages were received on the server. To view messages received on the server the WMQTT java utility was used. The battery used to energize the microcontroller was tested and it was seen that it could power the board for 6 hours continuously. In the process of sending the messages using MQTT it was observed and noted that around 5 percent of the battery was consumed for the act of publishing 1000 messages. Once the battery was used to publish the messages, it was used under normal operations and this yielded a 18-19 minutes of lesser operating time under normal circumstances.

	MQTT	**HTTP**
TRANSMISSION EFFICIENCY	(922/1024) 90%	(240/1024) 25%
BATTERY COSUMPTION (PER 1000 MESSAGES)	5%	18%

Table – 1 Comparison between HTTP and MQTT

VI. FUTURE SCOPE

The proposed paper is a basic prototype of the applications of using MQTT protocol for home and industrial automation applications. The paper can be extended to full fledged systems capable of interconnection of hundreds of sensors and many actuators. This approach requires efficient design of Brokers or Servers to meet the needs of the application. The following are a few applications intended for the future of MQTT

- MQTT can be used as part of a large sensor network capable of monitoring floods, volcanic eruptions and earthquakes achievable through the deployment of application specific sensors in disaster prone areas.
- The ideology of MQTT can also be extended to be part of a large network of energy monitoring systems. The basic ideology of Smart Metering can be extended to interconnect large number of meters to Brokers and form energy efficient solutions in order to build a smarter planet.

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- It can also be made part of a laboratory monitoring application wherein the system is capable of monitoring the necessary vital conditions for a user defined experiment.
- With great work and scope in the field of ubiquitous sensors and distributed systems MQTT can be made part of Supply Chain and logistics applications to increase the efficiency of existing systems.

The proposed application using MQTT is not developed in the full sense, it needs to undergo improvements and revisions and numbers of features of the protocol are to be improved. Some of the improvements of the proposed idea for Future Work are:

- Ideas like authentication of publisher or subscriber, encryption of published and subscription data, user name, password and RFID can be accommodated to improve the security of the system [10].
- Servers or Brokers specific to application can be developed to improve the communication efficiency and thereby improve system performance.
- Use of smart sensors with application specific boards can help in integrating large number of sensors using wireless mediums like Zigbee or RF to extend the sensing capability and perform better actuation in the specified application.

The proposed paper is implemented using basic applications with great usefulness and importance in public domain. The idea can eliminate the use of wired medium to design home and industrial applications. The smart metering can also eliminate human interference in water billing and control applications, and thereby effectively utilize the resource water and energy. Smart health monitoring has immense potential in health industry and thereby capable of reducing the risk of health hazards in home patients. It is an effective solution for reducing patient traffic at hospitals by scheduling the patient's appointment based on the measured body vital parameters. Our ongoing study is on optimization of energy consumption of the MQTT protocol system to design low power and battery operated applications.

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