Data Transmission Unit and Web Server Interaction to Monitor Water Distribution: A Cyber-Physical System Perspective

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***Abstract*— Cyber-Physical System (CPS) is the concept of converging physical devices with cyber systems, CPS shares environmental information globally and improves resource utilization. The major aim of our work is to use the CPS technology to overcome improper handling and care of water supply infrastructure. Our experimental water pipileing infrastructure test bed set up at National Institute of Technology Karnataka Surathkal (NITK), India includes analysis of water distribution in three storage tanks using minimal wireless communication technology. This requires monitoring and wireless networking of the monitored data. In order to obtain water usage of each storage tanks, we have proposed low cost customization of water pipeline infrastructure. Monitoring unit (MU) includes 865-867Mhz RF module. In this paper, we deal with the networking part of CPS to perform water monitoring distribution in each storage tanks. Networking of CPS includes communication between Data transfer unit (DTU) and Aggregator unit (AU) used in the MU and also communication between DTU and web server unit (WS). Communication between DTU and AU involves analyzing the amount of water flow in the Inlet and Outlet of storage tanks in the campus. The WS unit contains resultant data of water usage in each storage tanks. The extensive group of resultant data sets of water usage, obtained in each storage tanks, gives importance to data analytics. Initially, we came up with a small-scale experimental set up at NITK campus; which is then extended to large scale area. The waterflow rate graphs show average daily and monthly usage of water of each storage tank.**

***Keywords*— cyber-physical system; data transfer unit; aggregator; meter interface unit; monitoring unit; web server.**

I. INTRODUCTION

In recent years, water is considered as one of the valuable resources in INDIA, due to many reasons such as rapidly increasing population, pollution and lack of bulk water supply infrastructure. In INDIA as shown in Fig. 1, there is a huge scarcity of water resources to meet the basic needs of the population in India. A continuous supply of water is almost impossible. Even though a water service provider can manage demand for water using a system under continuous supply conditions, there is a minimum per capita demand for water for basic living needs. Supply and demand management is essential for the efficiency of a water service provider. Supply management denotes the activities that manage water on the supply end of a water service provider. Demand management denotes the activities used for the reduction of water usage by customers. The operation of water distribution service for continuous water supply is not effectively managed in India. Water supply provided is said to be continuous if water is delivered to every customer continuously in every day throughout the year, using an effective water distribution system [1].So in our experiment, we are customizing existing water pipeline infrastructure, in order to monitor water distribution to practice demand management. Storing water and preventing unbalanced water consumption are the major challenge in water management research. Effective steps need to be taken to control and reduce the water wastage from end users as well as from water resources. Undetected water leak in a pipe leads to huge water loss [2]. Thus, identifying the water leak in prior, by the aid of water management system decided improves balanced water utilization. For several years, water pipelines are deployed and maintained by human interventions, such as turning off or turning on valves of water pipes. It is known that the chance of water wastage is more because humans are prone to make mistakes. Thus, in this paper we come up with a water management system that monitors the water utilization in storage tanks, our experiment is done with available water pipeline infrastructure. By the help of this water monitoring system, water distribution can be tracked, and the amount of water consumed by the end user can be recorded. In our experiment set up, [3] customization of the existing water pipeline has been done to check up the water inflow and outflow details in storage tanks. In coming days,[4] [5] Cyber-physical system will become necessary to the human species, since wired control is bulky, uneconomical, requires large labor work and difficult to maintain. [6] Cyber-physical system, Internet of things and IPV6 envisages addressing every grain of sand on the surface of this planet with a unique ID. In this paper, we are considering the networking part of CPS to perform monitoring of water distribution system in storage tanks and discussing the communication between DTU and web server using minimal wireless technology.

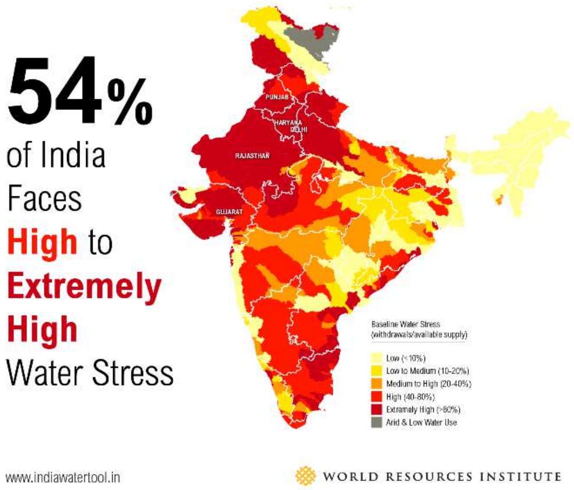

Fig. 1 54 percent of India's total area facing high to extremely high water stress. Source: www.wri.org/ http://www.indiawatertool.in/

II. Materials and Methods

A. Cyber Physical System

The term cyber-physical systems (CPS) was coined by Helen Gill at the National Science Foundation in the U.S. to refer to the integration of computation with physical processes [7]. Cyber-Physical Systems (CPS) are engineered systems whose operations are controlled by a computing and communication core. The desired characteristics of a well-designed CPS are a connected and coordinated distribution, robustness and responsiveness, adaptability, safety, and usability, with feedback loops including humans and the environment. This coordination between cyber and physical systems will be manifested from nano-scale to large-scale systems of systems [8].

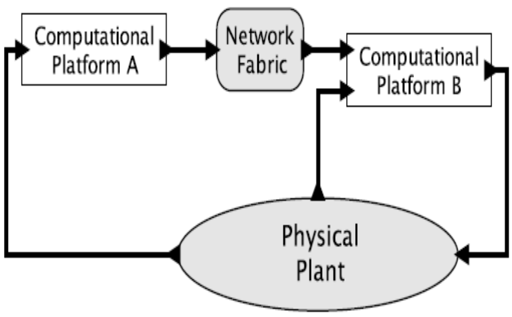

Fig. 2 Simple structure to understand CPS. [9]

Fig. 2 shows the simple structure of CPS [9]. Here, two platforms communicate with Physical plant through wireless devices like sensors, RF, and actuators and with each other through a network fabric. Platform B controls the physical plant via computation (sensor, RF, and actuators). Platform A makes additional measurements via computational (sensor, RF, and actuators) and sends the changes to Platform B through network fabric and controls the physical plant. So, it will be acting as a feedback control loop. [10].

Few of application of CPS include [11], [12]

- Healthcare
  - Surgery is done with real-time image guidance.
  - Analgesia inclusion pump controlled by patient.
  - Connectivity of medical devices using wireless technologies devices can be improved.
  - Surgery is done with the help of robotics.
- Automotive
  - With the use of sensors, accidents can be avoided.
  - Traffic congestion problem can be reduced.
  - By using a set of CPS techniques that can control autonomous vehicles providing the best possible routes, reducing accidents ,death caused by human being
  - With the help of CPS techniques, vehicles can be controlled by providing them facilities like routes, minimizing driver interaction in accidents and so on.
- Smart Power Grid
  - Monitoring the usage of charging and discharging of transformers in an electrical substation.
  - In a Smart grid system, balancing the power flow can be done.
  - Security attacks can be provided for energy infrastructure from outsiders.
- Avionics,
- Automation of Factory and Smart home management system, and soon.

B. 865-867Mhz RF module

In this work, we have used [13] 865-867 MHz RF module which provides robust wireless communication for all conditions [3]. The main advantage of this module is that with the help of serial data interface the module is suitable for adding wireless capability to any embedded devices. Other advantages include minimal power and provide reliability of data deliveries between devices.
The main features of this device are [13]:

- Supports point to point, point to multipoint and mesh topologies. (Here, star network is established).
- Support 2 FSK, 2-GFSK.
- Configurable transmit power up to 10dBm.
- Maximum RF data rate is 500kbps.
- Data reliability, acknowledgment mode communication, is used
- Source/Destination is addressing.
- Unicast and Broadcast communication.
- Analog to Digital conversion and Digital I/O line support.
- Power saving modes.

TABLE I.
SPECIFICATION OF 865-867 MHZ RF MODULE [13]

SL Num	Parameter	Details
1	**Power**	
i)	Supply Voltage	2.4 to 3.6 V.
ii)	Transmit Current	20mA@0dBm, 35mA@10dBm.
iii)	Idle/Receive Current	20mA.
iv)	Power-down Current	<10micro A.
2	**General**	
i)	Frequency	865-867MHz.
ii)	Nominal Transmit Power	10dBm.
iii)	RF Data Rate	2.4kbps to 500kbps(Max).
iv)	Receiver Sensitivity	-106dBm(at 9600 baud).
v)	Serial Data Rate	Up to 115200 baud.
vi)	Operating temperature	-40 to 85 ^{0} C.
vii)	Antenna Connector options	MMCX.
viii)	On-board Antenna	Spring Antenna.
3	**Network**	
i)	Supported network topologies	Point to point, point to multipoint, mesh topologies.
ii)	Addressing options	PAN ID and addresses.
4	**Mechanical**	
i)	Dimension	36mm *26mm.
ii)	Interface connector	2 * 10 pin berg stick, 2.00 mm pitch.

Source: www.melangesystems.com.

C. Proposed Experimental Set up

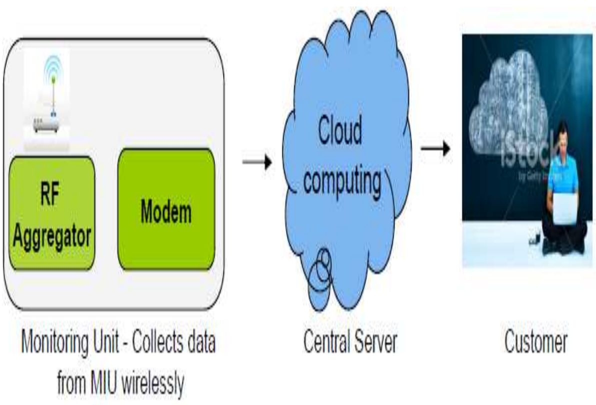

Fig. 3 Monitoring Unit. [2]

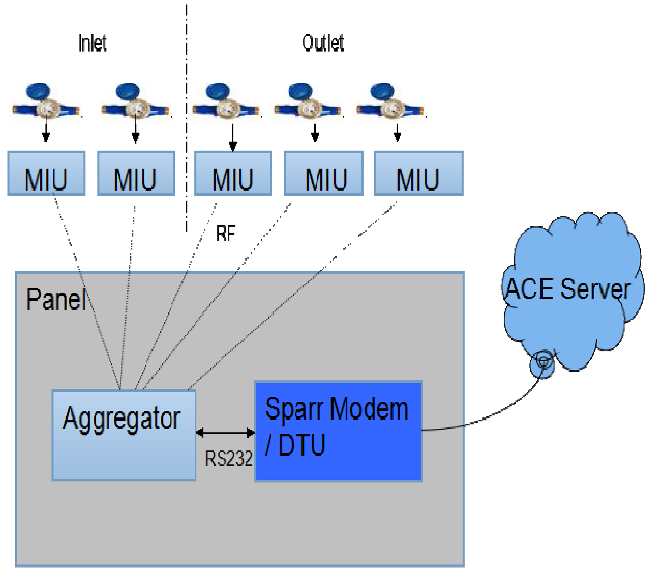

Fig. 4 Communication between MIU, Aggregator, DTU and Web server.

Fig. 3 shows the pictorial representation of monitoring unit which includes aggregator, DTU and web server. In each storage tank consists of MIU which includes water meter interfaced with a reed switch and an RF module to read water inflow and outflow details [3]. In the monitoring unit as shown in Fig. 4 is used to develop an automation solution that reads the water inflow and outflow parameters from each storage tank. Aggregator receives the water inflow and outflow parameters from each storage tank. An aggregator is interfaced to DTU with RS 232 port as shown in Fig 4. DTU is interfaced with an aggregator to read water inflow and outflow details and transmit the respective information to web server. Each storage tank will have one DTU, and DTU will collect information about water flow details from both inlet and outlet of the storage tank. For every 15 minutes, based on the water inflow and outflow details, DTU shall calculate the Water Pulse count for each Inlet ,Water Pulse count for each Outlet ,Total Pulse count for Inlet, Total Pulse count for Outlet, Net Volume of the storage tank. Finally, in ACE web [14], all the resulting information collected in DTU will be displayed.

D. Communication between DTU, Aggregator and web server

TABLE II.
PRE-DEFINED MIU ADDRESS TABLE [14]

MIU	Address
Inlet 1	0x00000001
Inlet 2	0x00000002
Inlet 3	0x00000003
Inlet 4	0x00000004
Inlet 5	0x00000005

Outlet 1	0x00000006
Outlet 2	0x00000007
Outlet 3	0x00000008
Outlet 4	0x00000009
Outlet 5	0x0000000A

1) Device Identification Message: The Device ID to include in the Device Identification message of DTU [14]. Example to understand Device Identification Message is shown below

i) Request Byte Stream Format
3CA10000000113100000000000000014C02EF0F0010001000000025B3E

ii) Byte Stream Format Split View
3C|A100|00|00|01|13|1000000000000014|C02E|F0|F001|0001|00000002|5B|3E

TABLE III.
REQUEST BYTE STREAM FORMAT [14]

Message header	Description	Length (bytes)
3C	Start byte (constant)	1
A100	Message code (constant)	2
0	Status, 0 – Success, >0 – Error	1
0	Indicates the total number of responses that shall follow the current message stream	1
1	No of parameters in this message (constant)	1
13	Total number of bytes following this (constant)	1
1000000000000014	Device ID	8
C02E	Device type	2
F0	Constant Value for Device Identification Data Packet	1
F001	Constant	2
0001	Parameter code (constant)	2
00000002	Application ID	4
56	FCS (^ operation on all message heads excluding the Start and Stop Bytes)	1
3E	Stop byte	1

2) Water Meter Parameters Message

i) Request Byte Stream Format
3CA10003000D0B07DC0F0505000737100000000000002001C02E01F02000010002000B000C00150018001B000043210000123400004563000032140000231300000ACFD000A4321xx3E

ii) Byte Steam Format Split View
3C|A100|03|00|0D0B07DC0F0505|00|07|37|1000000000002001|C02E|01|F020|0001|0002|000B|000C|0015|0018|001B|0000432100001234000045630000321400002313000ACFD000A4321xx3E

TABLE IV.
REQUEST BYTE STREAM FORMAT

Message header	Description	Length (bytes)	Type
3C	Start byte (constant)	1	Int
A100	Message code (constant)	2	Int
03	Status: 3 – Message with Retry counter and Timestamp	1	Int
00	Retry counter	1	Int
0D0B07D C0F0505	Time stamp in format DDMMYYYYHHMMSS (all in hex)	7	Int
00	Indicates the total number of responses that shall follow the current message stream	1	Int
07	No of parameters in this message = 4+ Inlet 1+ Inlet 2 + Outlet 1 + Outlet 2 and so on .	1	Int
37	Total number of bytes following this (Sum of bytes from Device ID to Meter Alarm status value)	1	Int
1000000000002001	Device ID	8	Int
C02E	Device Type	2	Int
01	Constant	1	Int
F020	Constant	2	Int
0001	Parameter code for Inlet 1	2	Int
0002	Parameter code for Inlet 2	2	Int
	And so on.		
0003	Parameter code for Outlet 1	2	Int
0004	Parameter code for Outlet 2	2	Int
	And so on.		
0005	Parameter code for Total Inlet	2	Int
0007	Parameter code for Total Outlet	2	Int
0008	Parameter code for Net Volume	2	Int
0101	Parameter code for Meter Alarm value	2	Int
004A1C44	Inlet 1	4	Float
0000DE44	Inlet 2	4	Float
	And so on.		
0080EFD0	Outlet 1	4	Float
00088B80	Outlet 2	4	Float
	And so on.		
00000036	Total Inlet	4	Float
00003296	Total Outlet	4	Float
0000FF69	Net Volume	4	Float
00	Meter Alarm status value	1	Int
8F	FCS (XOR ^ operation on all message heads excluding the Start and Stop Bytes)	1	Int
3E	Stop byte	1	Int

3) Response Byte Stream Format:

DTU shall wait for the acknowledgment from the server after sending the message. The server sends either a SUCCESS or FAILURE message. The Response sent out by Web server shall be either Success or Failure as shown in Table V and Table VI respectively. The Byte Stream Format shall be as below

- Success: 3CA1000000A13E
- Failure: 3CA1000200A33E

i) Success: 3C|A100|00|00|A1|3E

TABLE V.
SUCCESS RESPONSE BYTE STREAM FORMAT

Message header	Description	Length (bytes)
3C	Start byte (constant)	1
A100	Message code (constant)	2
0	Status: 0 – Success	1
0	Indicates the total number of responses that shall follow the current message stream	1
A1	FCS (^ operation on all message heads excluding the Start and Stop Bytes)	1
3E	Stop byte	1

ii) Failure: 3C|A100|02|00|A3|3E

TABLE VI.
FAILURE RESPONSE BYTE STREAM FORMAT

Message header	Description	Length (bytes)
3C	Start byte (constant)	1
A100	Message code (constant)	2
02	Status: >0 – Error	1
00	Indicates the total number of responses that shall follow the current message stream	1
A3	FCS (^ operation on all message heads excluding the Start and Stop Bytes)	1
3E	Stop byte	1

III. RESULTS AND DISCUSSION

The communication in the monitoring unit has been achieved successfully. The connection between DTU, aggregator and web server are working as needed. The request and response byte stream format for success and failure messages are communicated accurately between DTU and web server. Finally, we are able to display the water flow details from the inlet and outlet and also the net volume of the storage tank in the web server as shown in Fig. 5 and Fig. 6. With the available water flow data, we have the following strategies towards data analytics. In Fig. 5, we are monitoring the monthly usage in a single storage tank. In Fig. 6, we are monitoring the daily usage in a single storage tank. Since data analytics plays a significant role in computing and actuation part of CPS, We hope that these challenges and issues bring enough motivation for future discussions and interests of research work on CPS.

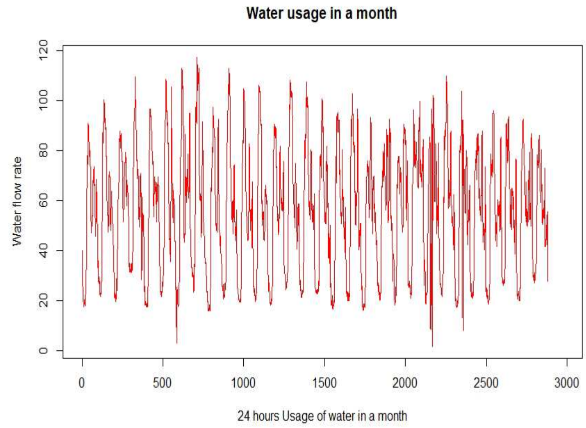

Fig. 5. Monthly usage of water in a Storage Tank.

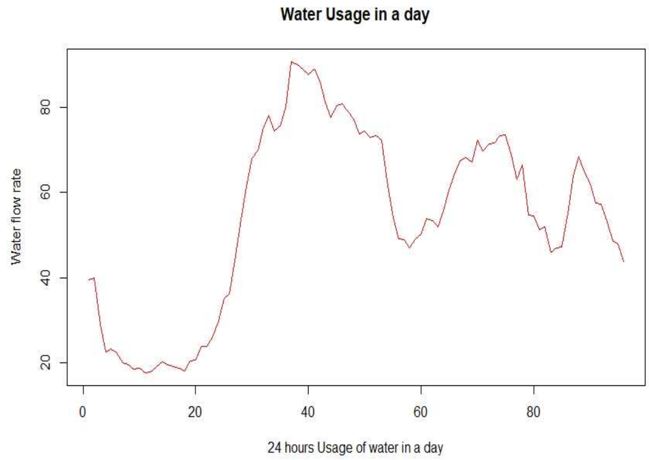

Fig. 6. 24 hours Usage of water in Storage Tank

IV. CONCLUSIONS

The contents of this paper acknowledges the data interaction between Data Transmission Unit and web server. This paper has greatly deliberated on networking part of CPS. The extensive group of data sets obtained in each storage tanks gives importance to data analytics. Data analytics plays a major role which contributes for the promotion of CPS integration in campuses. The future work is planned towards CPS simulation by building data analytics model which ensures proper water management.

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