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Machine to Machine Communication Protocol for SMART Manufacturing Units

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Abstract. This paper explores the need for a true Machine-to-Machine communication protocol without the need of intermediate servers, to allow machines to communicate with one another in a decentralized manner, while offering a lower latency and transmission time than existing protocols. The communication protocol is developed with Siemens Siematic S7-1200 modules that will communicate within different networks and benchmarked against the existing protocols. The results show that a decentralized communication protocol can be implemented with reduced latency and transmission time, while offering critical characteristics needed to realize SMART Manufacturing within real-time for a production line.

1. Introduction

Research and development within Industry has seen the need for future manufacturing systems to be flexible and adapt to the manufacturing needs of Industry 4.0 [1].

This flexibility within the manufacturing line comes in the form of machines and equipment being able to swap in and out of a production line in order to meet the needs of Industry 4.0 ready products.

The ability for machines to be able to swap in and out whilst still containing order in a production line is possible with machine to machine communication. Traditional machine to machine communication makes use of intermediate servers housing, decoding and transporting messages between machines.

These communication protocols offer a high flexibility between machine vendor modules but suffer with the ability to transport messages in real-time. The inability of these communication protocols to communicate in real-time, have seen them be excluded in Industry 4.0 [2].

This paper asserts that in order for SMART Manufacturing systems to realize a real-time decentralized operation within a production line, a communication protocol is needed [3]. The detached characteristic in communication will allow for machines to actively respond to changes in the environment in real-time.

This project situates two SMART Manufacturing Units in a water bottling plant, where water bottles are filled based on their volume and capped based on the size of water bottle. Orders are collected through an online app, where customers may customize their order with unique bottle designs for 300 ml and 500 ml water bottles. Orders are then optimized for production and sent to a central Open Platform



Communication (OPC) sever where each order is communicated and update to each machine. Each machine then communicates to each other machine during production about production status and machine status.

2. Literature Review

2.1. Industry 4.0

Industry 4.0 [4] is the emergent industrial revolution of the 21st century that incorporates the technologies and industrial standards of next generation engineering. The key pillars of Industry 4.0 are SMART Manufacturing (SM), Internet of Things (IoT) and Cyber-Physical Systems (CPS). The aim of Industry 4.0 is to achieve product customization and assembly line integration for greater information with products use.

2.2. SMART Manufacturing

SMART Manufacturing (SM) [5] encompasses the means necessary to ensure fluid and intelligent decision making during the production process. This is done by monitoring a products' life cycle, even well after the production process and by communicating to the other entities in the environment. These entities can comprise of the physical machines, factories or even products themselves.

The information gathered from the environment is to be communicated to either singular machines or the environment itself. The characteristics [6] that enables manufacturing to be classified as SMART and possess intelligent decision making is; Composability, Cyber-Security, Data Analytics, Cloud Manufacturing, Interoperability and Contextual Awareness This is depicted in Fig 1.

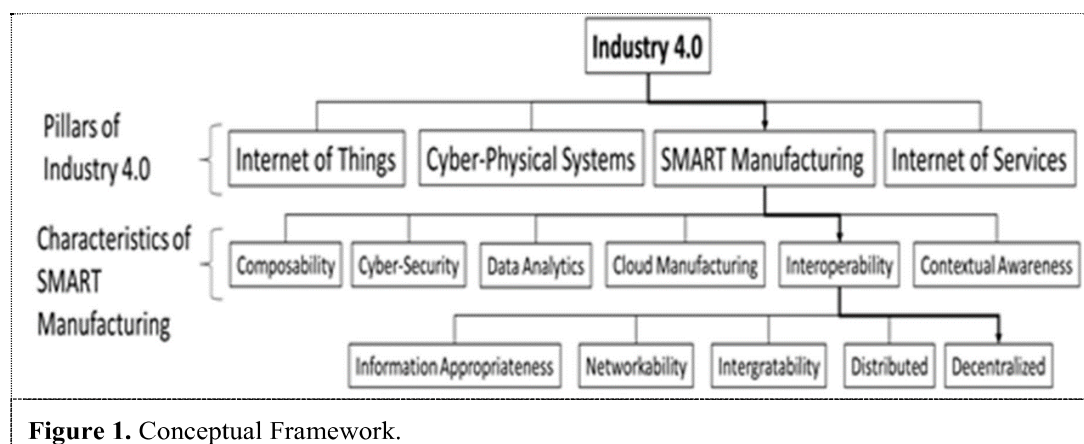
2.3. SMART Manufacturing Units

SMART Manufacturing Units (SMU's) are the enabling technology [7] of SMART Manufacturing where the units possess a subset of the characteristics outlined in Fig 1. For the purpose of this paper, the communication between SMU's is focused with special importance placed on the decentralized attribute of the interoperability characteristic.

This interoperability characteristic of SMU's also includes; Information appropriateness, Networkability, Interpretability and Distributable. These characteristics are ideally handled by a communication protocol and network.

2.4. Machine to Machine Communication

Machine-To-Machine (M2M) communication [8] in use, such as Open Platform Communication (OPC) [9] and WebSocket [10], rely on intermediate servers to facilitate the communication transfer between



machines. This trickles down to a wide variety of machine vendor's using different means of communication and underpins the need for an integrated communication between singular machines.

Current methods of M2M include OPC, WebSocket and MQTT. OPC uses a dedicated server to host the communication between different vendor machines. OPC therefore acts as an intermediate server to facilitate communication by, decoding messages and encapsulation the message to be sent to various other vendors.

This is done due to the incompatibility of unlike machines being able to communicate to each other. Instead the information of a sent message needs to be de-capsulated, decoded and encapsulated to the next machines communication protocol.

OPC is seen as a pick and swap storage of multiple communication protocols, for multi-vendor communication. The drawback however is the latency and high communication time needed in decoding and encapsulation of messages for the advantage of being robust.

WebSocket stems from similar method of the Hyper Text Transfer Protocol (HTTP), the majority carrier protocol of the internet. With both protocols situated in layer 7 of the Open Systems Interconnection model (OSI model), both rely on handshake agreements.

This handshake is seen as a back and forth communication to verify that communication may take place, is taking place and has taken place successfully. Although Websocket offers a lower overhead during communication, than that of HTTP, the amount of overhead and the need for vendor specific machines, see's WebSocket fall out of use in modern day M2M communication.

MQ Telemetry Transport (MQTT) is a lightweight communication protocol, developed for M2M communication for less intensive coding environments. Although MQTT excels at communication in remote areas, and speed through low bandwidth messaging, MQTT is unable to satisfy M2M communication protocols in the Forth Industrial Revolution.

With MQTT unable to store large quantities of information per message, MQTT has been left out of SM communication due to the need for big data and analytics from SMART Manufacturing. As seen in further sections of this paper, MQTT often excels at sending individual messages at best possible speeds, with no need for handshaking.

Furthermore, due to the lower bandwidth per message, often more messages will need to be sent in order to deliver the same amount of information from one message. This reinstallation of establishing connection, packaging messages and queuing often sees MQTT produce a higher latency and transmission time to deliver equally sized messages.

With I4.0 needing a right amount of bandwidth sending but staying within the bounds of real-time communication and multi-vendor messaging, better and more well-equipped communication protocols need to be established.

However, with Industry 4.0 becoming more flexible within the production line and the ability for machines to swap in and out, the communication within a production line of different machines is needed to react in real-time and with as little latency as possible.

This implies that traditional M2M communication protocols have seen outdated methods for means of communication and a true M2M communication protocol without intermediate servers is needed [11]. These protocols will help realize real-time, low latency communication in order to succeed in Industry 4.0.

3. Methodology

This paper uses a SMU that has an attached Siemens S7-1200 module that is tasked with the filling of different size water bottles. This SMU will then communicate with a standalone S7-1200 module for testing of the M2M communication protocol.

The first layer of the OSI model is concerned with the physical layer. This layer is responsible for the physical structure of the network (topology) made up of the different hardware devices and link between them. A communication network can be realized with a single connection existing between each machine, but with the redundancy and hardware cost of amount of links existing between each machine becoming expensive, a switch can suffice as a solution to both cost and addressing scheme. This switch is where the M2M communication protocol can share a similar addressing scheme as the standard IPv4 internet protocol.

Although in this case there is a switch linking the two S7 modules, as seen in Fig. 2, this switch serves only as a means to allow multiple access points for future SMU's. This switch does not any anyway act as a server to facilitate, decode or extract the information sent from machine to machine. Alternatives would call for expansion models to be attached to every SMU for multiple Ethernet access.

The switch only acts as a forwarding node of information to facilitate the exchange of information from machine to machine. The S7-1200 modules and communication protocol were programed in Totally Integrated Automation (TIA) portal.

3.1. Plant Set-up

Within the water bottling plant production line, two SMU's exists to fill the custom water bottle with either 300 ml or 500 ml of water and to cap each custom water bottle. The first SMU uses image processing to determine the shape and volume of the bottle, and then fill the water bottle with the correct amount of water. The height of the bottle can then be extracted from SMU 1 and communicated to SMU 2 in order to gain the correct height placement for the capping process.

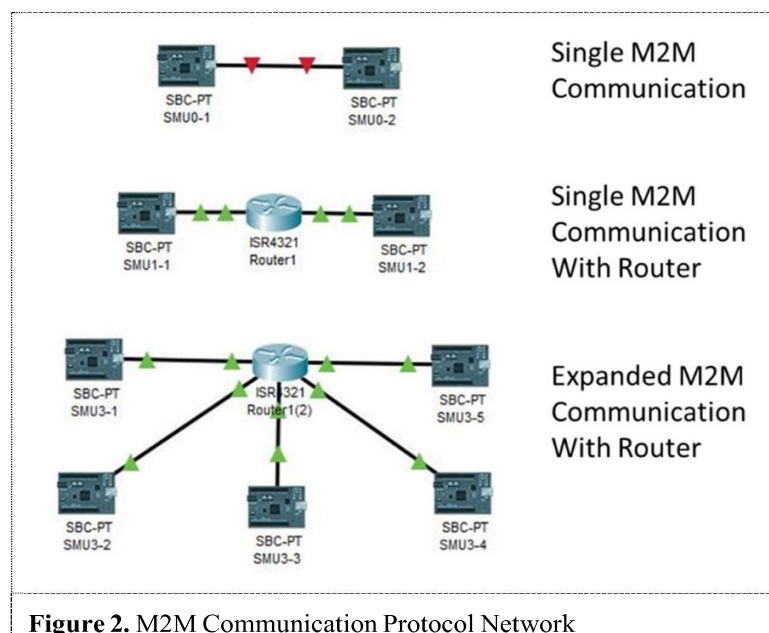


Figure 2. M2M Communication Protocol Network

Table 1: Communication Method

	4	4	4	4	4		
0	Method	Destination		Version			
1	Header Field Name		Value				
2	Header						
3							
4	Header Field Name		Value				
5	Blank Line						
6	BODY						
7							
8							

3.2. SMART Manufacturing Units

The paper utilizes two SMU stations communicating through a switch. As previously mentioned, the switch only serves as a multi-access port plug in the expansion of the network and plays no point in transporting or encapsulating the communication protocol.

The SMU's used in this study are controlled using Siematic S7-1200 PLC's. This network can be expanded in the future to accommodate larger production lines, however this paper's focus is to analyze the effectiveness of the communication protocol as well as measure the latency and transmission time of the communication protocol. These aspects would be the easiest to monitor with a scaled down network.

3.3. Communication Method

Within the communication protocol there are two major aspects, the Communication Method and the Communication Information. The communication method is used to decide on how information is sent. The communication information will decide on what information is sent.

The method includes the addressing scheme of the protocol, the structure and version of the protocol and an encapsulation of the message information sent from the communication information. The structure of the communication method can be seen in Table 1.

1) Method

The protocol is designed to use similar methods of the HTTP protocol, namely: GET and PUT. The PUT method is used to assign information from one S7 SMU module to another. The GET method is used to retrieve information from a S7 SMU module. These two methods are then used on a trigger basis to receive information about another SMU and bring in-line the contextual awareness characteristic of SMART Manufacturing. As in contrast to other communication protocols, such as HTTP, where a handshake agreement is needed for exchange of information, the GET and PUT methods have reserved memory only accessed by other communicating devices.

2) *Destination*

The destination field specifies the host device/ server of which the method would transfer the information to. This field only specifies the direct device and not the location of where the information to be stored. The actual location within the device where the information is stored, is handled in the BODY field. The destination field works similar to that in other communication protocols, such as HTTP, where in the 3rd layer of the OSI Model, namely the Network layer, handles all destination and source information. The addressing scheme for the SMART Manufacturing Protocol (SMP) implemented works similar to that of the IPv4 protocol, where each device is given one of a unique 2^{32} possible addresses. These addresses can be divided up for different subnet and different networks of devices.

3) *Body*

The Communication method is then used to communicate the BODY of the message which contains the Information of the SMU. The BODY contains the Machine Type, Machine Status (Flags) and any data a user wishes to communicate between devices. Each of these fields is accompanied with a unique 8-byte address that is stored onto the SMU.

This unique address is used to either update only a certain portion of the communication from the PUT method or retrieve a certain portion of information from the GET method. Therefore, not the entire body of information needs to be retrieved, if not updated, to reduced latency.

3.4. *Communication Information*

The information Communicated is used to communicate the actual information about the machine. This information is used to allow other machines to acquire information about surrounding machines and their environments. This adds to an expanding network where each machine is able to realize every other's machines environment, bringing about a contextual awareness for the machines and the environment.

This contextual awareness through the communication of the protocol will allow the machines create intelligent decisions and become SMU for SMART Manufacturing. The communication information that would be emasculated into the DATA field of the communication method can be seen in Table 2.

1) *Machine Type*

The MACHINE TYPE field is used to identify the types of machines that exist within the production line. Since there is a finite amount of types of machines that exist, this field could be used in a lookup table to allow machines to reference the type of attached machine next to itself.

This will allow machines the ability to decide if a current product on the production line can be manufactured with the types of machines attached on the production line. Similarly, if products would require special manufacturing instructions, then the machine can easily decide what type of machine is the product needed to be directed to with the MACHINE TPE identifier.

Table 2: Communication Information

	8	8
1	MACHINE TYPE	MACHINE STATUS
2	DATA	
3		

2) *Machine Status*

The MACHINE STATUS field houses all of the flags of the machine. These flags include information about the current machine. For example, if the machine is able to continue with the current production, if the machine would require maintenance, if there are communication issues or other factors affecting the functioning of the machines.

Since the communication protocol is designed using inspiration of HTTP GET and PUT methods, a machine could gather information about the surrounding machines for if production is able to continue and be completed. This will lead to machines being able to decide whether to continue or halt production or to even work at a reduced/increased production pace.

3) *Data*

The data field of the communication protocol is left open for user specific information to be sent. With the case of the IPv4 protocol this field would typically contain the information sent to decode a YouTube video, or populate a website that is loading. Therefore, this information would typically contain information about the machines' sensors. This information can then be passed onto machines on a conveyor to trigger events to continue production.

4. Results

The communication protocol is tested with two parameters but is still discussed in the sense if the protocol is able to be applied to assist in SMART Manufacturing. The two parameters that is tested is the Transit Time and Latency of the communication protocol.

4.1. *Transit Time*

With the transmission time of a protocol being the time taken for a message to be sent and received, the developed SMART Manufacturing protocol (SMP) was tested to have about 15ms transmission time, tested at standard conditions. This transmission time of the SMP is on par with most communication protocols and is less than both OPC and WebSocket, as seen in Fig. 3.

4.2. *Latency*

With the latency of communication being the down time between which two messages can be sent between devices. It is clear to see that the newly developed SMP, on the far right of Fig. 4, has a considerably lower latency compared to OPC and better latency compared to WebSocket.

With OPC and WebSocket being the main two communication protocols in use with M2M communication, it is also worth re-noting that the SMP protocol does not require an intermediate server, unlike its predecessor.

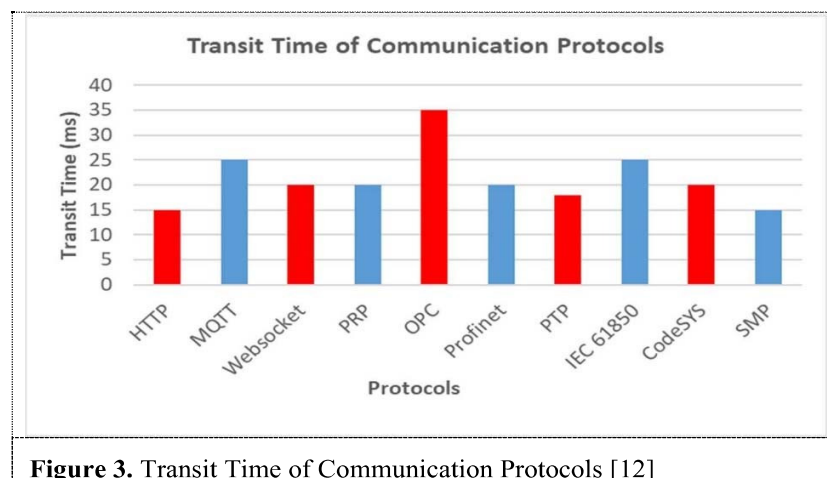


Figure 3. Transit Time of Communication Protocols [12]

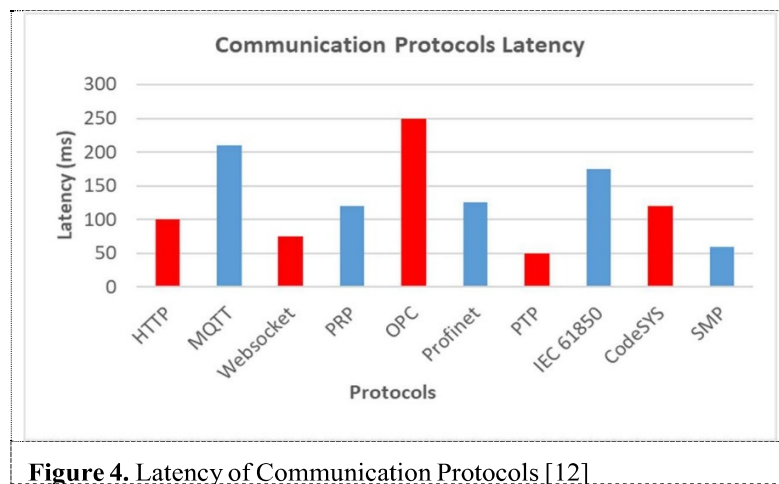


Figure 4. Latency of Communication Protocols [12]

The reason for the lower latency in the SMP when compared to WebSocket and OPC, is due to the lack of acknowledgement and checksum fields in the SMP protocol. Since the OPC has redundant acknowledgment fields and waits for returns on the original message, scaling networks with use of OPC usually see increasing latency issues.

However, it is seen as the machines responsibility to ensure the accuracy of information received, whether through multiple GET methods or multi-host comparison. Even with a threefold repeat of the GET method, the latency will still be lower than that of OPC.

4.3. Communication

With the communication protocol using similar HTTP GET and PUT methods, communication is seen as a server communication with a device. However, since each device has both methods, each device is seen as server.

Centralized communication exists when multiple host connect to a single server, where the server has PUT method administration rights. Since each device acts as a server however, each device has decentralized operation as the server/machines is able to store as well as sends/transmits data to other hosts.

5. Conclusion

This paper explores the need for a true Machine-to-Machine communication protocol without the need of intermediate servers, to allow machines to communicate with one another in a decentralized manner, while offering a lower latency and transmission time than existing protocols.

As part of the study, the paper examines communication protocols such as; OPC, WebSocket and MQTT as well as the characteristics making up SM. These characteristics revolved around Decentralization, Networkability, Interoperability, Information Appropriateness and Distributed. These characteristics could be achieved with effective communication, rooting from a well-defined communication protocol. While previous communication protocols proved effective in their own right with either low latency or effective transit time, they lack requirements for SM. These requirements revolved around Big Data, effective transit time and low latency bringing to shape real-time communication.

A communication protocol is then developed between two (however still scalable) Simatic S7 1200 modules, acting as SMU's. The communication protocol formed similar as the HTTP protocol, with major differences coming in the Transport and Network layer of the OSI Model. These changes included the methods for information transmission and information sent. This included the GET and PUT methods.

With the SMP providing a lower latency and lower transmission time than most in use communication protocols (depicted in Fig. 3 and Fig. 4), while abandoning the need for an intermediate server, the protocol can be used in real-time communication for manufacturing. With the ability of the protocol allowing each device to act as a server and creating a decentralized network, information to create intelligent decision from machines and gathering contextual awareness from attached machines and the environment can bring about SMART Manufacturing Units to realize Industry 4.0 needs. Future aspects would be to include multi-vendor devices within the network using similar methods.

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