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## IOT LOW BANDWITH NETWORKS M2M COMMUNICATION PROTOCOLS REFERENCE QUALITIES

*The evolution of the Internet has been a four-stage process thus far. It began with basic connectivity, then moved to a network-economy, then immersive experiences, and is now at a fourth stage, which is IoE (Internet of Everything). The Internet of Everything is not a tangible term. Rather, it is the connections between people, processes, data and things that create more valuable and relevant experience, tuning information into actions that create new capabilities and unprecedented economic opportunity. The aging society is one of the reasons why IoE essential, to enable people live alone, without assistance, longer. IoE goes beyond a broad range of Machine-to-Machine (M2M) technologies and protocols. However, the main constraint of most existing platforms is their limited mutual interoperability. In this paper, we observe protocols suitable to support IoE philosophy and value its current state. As a result of our investigation we identify qualities and criteria's that should be achieved to satisfy needs of M2M communication in a low bandwidth network. Comparison show that creating new protocol based on CoAP for Ethernet connections and capable to transfer messages using SMS as a transport as well as adding message sequence feature should solve existing technology gap.*

**Keywords:** Emergency, Monitoring, Publication, Subscription, Protocol, Raspberry PI.

### Introduction

In the modern age, it is hard to imagine a day without humming sensors, actuators, and smart meters. None of them isolated anymore. The goal, is to connected them together and make our life and business easier. In the past, we expect that people shall take an action first. In difference, now when IoE becoming our reality, we would like smart sensor and technologies to take an intelligent decisions and act on behalf of us. This expectation is dictated by the global trend of aging society and our will to help people who could not use phones, smart devices due to physical inability. As example, seniors suffering from heart attack may not be able to ask for an ambulance, child who stay alone at home or play in the courtyard may not be able to ask parents for help. List of such kind of scenarios could be expanded [1–2] however, self-help ability in all of them were connected with three key constraints:

1. Person has a physiological ability to invoke information transfer.
2. Person transferring data understand how to use digital technologies.
3. Affordability and ability to carry everywhere (like watches).

Technologies and platforms implementing IoE philosophy and values expected to solve above constraints, enabling for most unprotected social groups new digital experience that any of us could have ever imagine before.

Yet another well-being improvement could be en-

abled by engaging state emergency services with new tooling able to provide reliable communication in the most dangerous places like fireman tackling with wild-fire. Worth to mention that military service could also improve its quality by enabling relevant procedures and tooling during tasks execution out of the base location and battle zone.

**After considering existing works** it becomes clear enough that technology intelligence and ability to process and maintain devastating amount of sensor data require new breath-taking approach to well know paradigms and principles, like data compression and M2M data exchange. There were lots of investigation and reports published recently that proof necessity of a new M2M data exchange approach design [3–5].

**Major issue** is that most of existing protocols and technologies applicable for IoE (similarly to IoT) lack qualities balance – either lack QoS, either have transport layer dependency, either send lots of redundant information and so could not be used in constrained environments without extraordinary tricks and limitations.

We believe that M2M communication and data exchange should enable an opportunity rather than create a constraint.

**The Goal of Research** is to estimate reference qualities for the M2M protocol and design a solution able to provide extend existing approaches with ability to control message sequences and support SMS as a transport.

## Statement of basic materials

### Conceptual and technical decision

Since the system is designed primarily for ordinary citizens and public institutions, cost of the final decision is very important. The number of users can be very large, as a result capacity of individual components and the possibility of horizontal scale is one of the major constraints. Personal data processing compliance for the processor and data collector piece of the system should be addressed appropriately [6]. Also, of a great importance is reliability of the connection, namely the ability to use, all available telecommunication channels for the transmission of individual message. Low power consumption is needed first of all to meet the end user's need to use the equipment in a moving state, without need for constant recharging. The compactness factor - small size of the device is also significant because the user must be able to move along with it (for example, put it in a pocket). In this regard, coverage also matters, the button in the user's pocket should be able to transmit the message at the most possible distance from the gateway.

Based on described criteria solution for the main goal consists of next key components (Fig. 1):

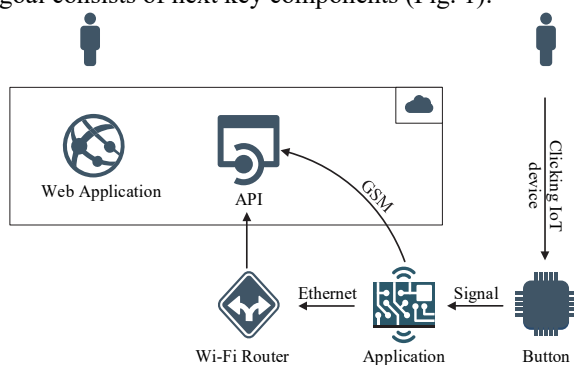


Fig. 1. Conceptual system architecture

1. Web application and services providing connection to recipients with free user preferences deployed to cloud.

2. SMS Gateway receiving SMS messages and re-sending them to cloud.

3. Station receiving messages from end-user devices and deciding where and what is the right way to resend (directly to cloud or alternatively due to cloud unavailability and other reasons send SMS message to SMS Gateway).

4. Device with Button – reference designation for the end-user device carried and has a button to be pressed at any moment.

### Existing approaches overview

Major constraints related to IoT solutions design are described in Fig. 2. The majority of technologies are allowing to choose only 2 qualities from the list: Long Distance, High Speed, Low Power. For example, Blue-

tooth lacks distance but has low power and average speed. LoRa has long distance and low power consumption but low speed. Given that our intent is to built solutions for the large group of users in locations that may lack coverage of 3G\4G LTE networks or Wi-Fi connectivity it is obvious that LoRa would be the best baseline technology. As a fallback 3G\4G LTE networks or Wi-Fi could be used to transfer data. In the situation when non is available we still could give a try to send SMS messages. Latter definitely has the best coverage and would be available in the majority of locations.

Obvious message exchange is a mission critical piece that would have significant impact on overall solution performance and qualities. Moreover, it should be adopted to be used with different transport layers able to switch transparently from one to another. Giving above examples it is clear that size of frame with data for SMS messages used as transport layer and Wi-Fi connectivity is different.

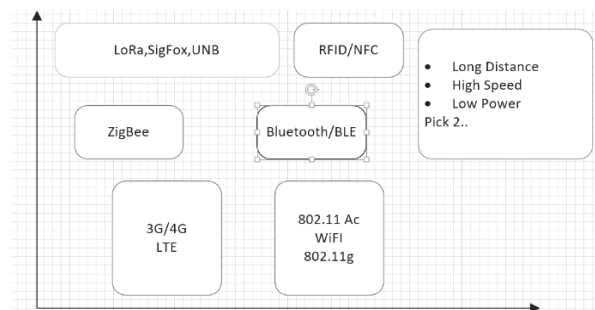


Fig. 2. Dependency between Range, Distance and Power

After observation of existing researches [3–5] and proposed architecture, we decided to start from designing reference protocol qualities. This should give us a direction how the protocol for message exchange should look like. Moreover, we should create specification for protocol messages and data exchange rules – authorization messages, data transfer messages.

Generally, IoE protocols are separated based on the network segment being used: machine-to-machine, machine-to-sensor or sensor-to-sensor. Based on the network topology used some of them might be not applicable at all or overcomplicated. The most well-known and popular protocols for M2M connections with IoT sensors implementing client-server architecture will be:

**CoAP** – The Constrained Application Protocol [7] is a specialized web transfer protocol for use with constrained nodes and constrained (e.g., low-power, lossy) networks. The nodes often have 8-bit microcontrollers with small amounts of ROM and RAM, while constrained networks such as IPv6 over Low-Power Wireless Personal Area Networks (6LoWPANs) often have high packet error rates and a typical throughput of 10s of kbit/s. The protocol is designed for machine-to-machine (M2M) applications such as smart energy and building automation. CoAP provides a request/response

interaction model between application endpoints, supports built-in discovery of services and resources, and includes key concepts of the Web such as URIs and Internet media types. CoAP is designed to easily interface with HTTP for integration with the Web while meeting specialized requirements such as multicast support, very low overhead, and simplicity for constrained environments.

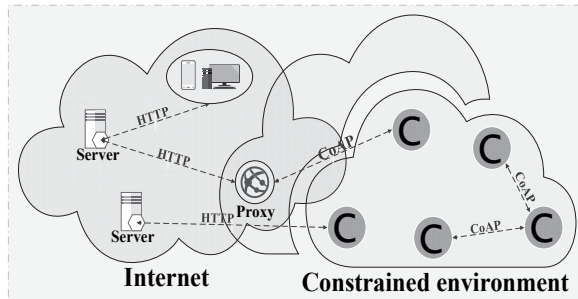


Fig. 3. CoAP Architecture

**MQTT-SN** – MQTT-SN is designed to be as close as possible to MQTT, but is adapted to the peculiarities of a wireless communication environment such as low bandwidth, high link failures, short message length, etc. It is also optimized for the implementation on low-cost, battery-operated devices with limited processing and storage resources. Compared to MQTT, MQTT-SN is characterized by some differences outlined in [8]. MQTT (Message Queuing Telemetry Transport) [9] is an ISO standard (ISO/IEC PRF 20922) publish-subscribe-based messaging protocol. It works on top of the TCP/IP protocol. It is designed for connections with remote locations where a “small code footprint” is required or the network bandwidth is limited. The publish-subscribe messaging pattern requires a message broker. Andy Stanford-Clark of IBM and Arlen Nipper of Cirrus Link authored the first version of the protocol in 1999 [10]. In 2013, IBM submitted MQTT v3.1 to the OASIS specification body with a charter that ensured only minor changes to the specification could be accepted. Historically, the “MQ” in “MQTT” came from the IBM MQ (then ‘MQSeries’) message queuing product line. However, queuing itself is not required to be supported as a standard feature in all situations.

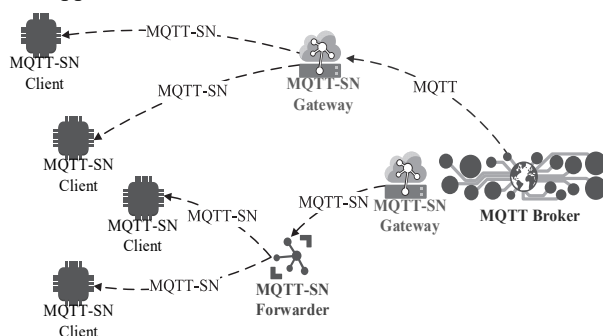


Fig. 4. MQTT-SN Architecture

**XMPP** – Extensible Messaging and Presence Protocol [11-13] is basically an open technology for real-

time communication, using XML (Extensible Markup Language) as the base format for exchanging information. It was designed to be easily extensible, and one of its main uses are publish-subscribe systems. Throughout its history, it was used by companies such as Google (in the GoogleTalk communicator), by Microsoft (in Skype), and by Facebook (in WhatsApp Messenger). The idea behind XMPP is similar to that of e-mail, with a distributed server network in which each and every server can create its own service. The XMPP standard enables message encryption, and XML support allows for the use of such technologies as SOAP or EDI (Electronic Data Interchange). A standard that is tightly coupled with XMPP is SOAP over XMPP, which can be tested using the same means, as sending a SOAP message is basically sending some content over XMPP. This standard provides effective and reliable messaging – both asynchronous and synchronous [14–15].

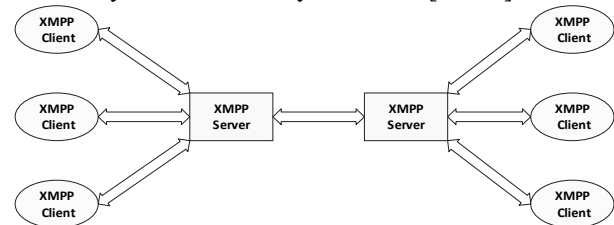


Fig. 5. XMPP Architecture

**STOMP** – is a simple interoperable protocol [16], it is a frame-based protocol, with frames modelled on HTTP. A frame consists of a command, a set of optional headers and an optional body. STOMP is text based but also allows for the transmission of binary messages. The default encoding for STOMP is UTF-8, but it supports the specification of alternative encodings for message bodies. A STOMP server is modelled as a set of destinations to which messages can be sent. The STOMP protocol treats destinations as opaque string and their syntax is server implementation specific. Additionally, STOMP does not define what the delivery semantics of destinations should be. The delivery, or “message exchange”, semantics of destinations can vary from server to server and even from destination to destination. This allows servers to be creative with the semantics that they can support with STOMP. A STOMP client is a user-agent which can act in two (possibly simultaneous) modes:

as a producer, sending messages to a destination on the server via a SEND frames

as a consumer, sending a SUBSCRIBE frame for a given destination and receiving messages from the server as MESSAGE frames.

### Message transport analysis

Transport layer obviously makes significant difference between protocols. The most recent researches [17] show that TCP perform a little better than UDP even in constrained environments. Another research [18] show

that the optimal transport layer is represented by DCCP. It is important to note that latter take an assumption that lost packages lack sense to be sent again, because they will not provide value to consumer.

To understand better transport issue with existing protocols we decided to do a set of simulations. Generally speaking, data produced by IoT sensors could be classified into several groups:

**Package** – photos would be best sample.

**Streaming data** – temperature sensors, GSM data. For this group getting latest data always make more sense than waiting for lost packet.

**Volatile streaming data** – like accelerometer values. Getting latest data still important. But losing a packet may produce false-positive results on analysis stage.

**Compressed data** – application level compressed data.

We've decided to start from package and compression scenario. An image on Fig. 6, Fig. 8 were selected for analysis. Images were pre-processed and pass through following cases a) 5% data loss b) 5% data loss and 5% data order change c) 5% data loss replaced with zero (Fig. 7. and Fig. 8).



Fig. 6. Original JPG Image (Compressed data)

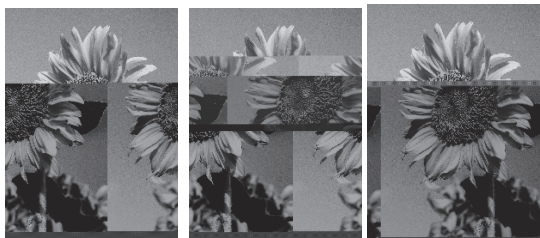


Fig. 7. Case a), Case b) and Case c) for JPEG



Fig. 8. Original and Case c) TIF image

Obvious conclusion that any compression done on application level is sensitive to data loses and packets order. Non-compressed images for case a) and case b) were broken, however replacing lost packages bytes with zeros allow to get best result. Another conclusion is that sequence number for messages increase quality of data transmission.

For streaming and volatile streaming data type we

could use Pearson correlation coefficient for quality assessment.

$$r_{XY} = \frac{n(\sum XY) - (\sum X)(\sum Y)}{\sqrt{[n\sum X^2 - (\sum X)^2][n\sum Y^2 - (\sum Y)^2]}}. \quad (1)$$

Streaming data simulation was concluded for the same set of cases and as a source we pick up 20 days daily average temperature (Fig. 9–11).

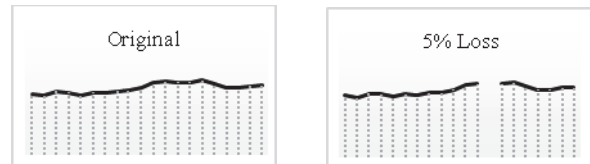


Fig. 9. Original and Case a)

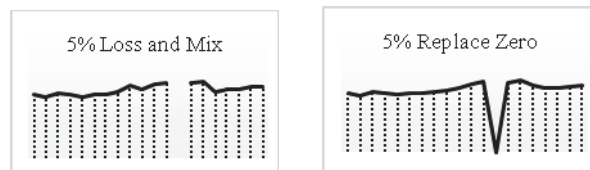


Fig. 10. Case b) and Case c) Zeros

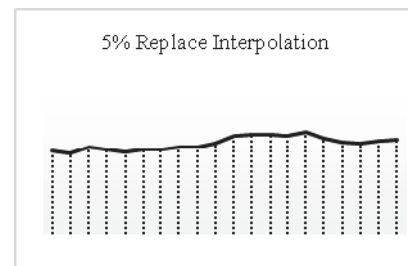


Fig. 11. Case c) Interpolation

To be able to calculate coefficient we will add next available value to the end of dataset in the situation when we have losses and could not identify position of lost packages.

Table 1

Streaming data results

Experiment	$r_{XY}$
5% data lost	94%
5% data lost and 5% data mixed	78%
5% data lost and replaced with Zero	1%
5% data lost and Interpolation	99%

Similar to previous examples package sequence significantly improve quality of service. Defaulting lost packages bytes still works, but now it is clear that default value should be selected case by case. Mixed packets show most inadequate results, which is not so bad for systems interested in latest data, but would impact retrospective analysis and ability to predict future values based on historical data.

As an example of streaming volatile data, we use accelerometer  $X$  axis input, similar to previous evaluation we use Pearson correlation for assessment and use

next value available to replace gap when we do not know position of lost item (Fig. 12–14).

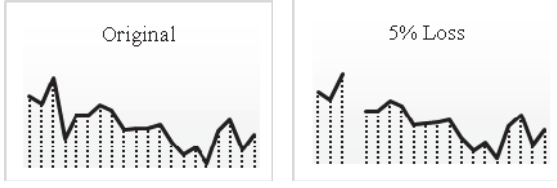


Fig. 12. Original data and Case a)

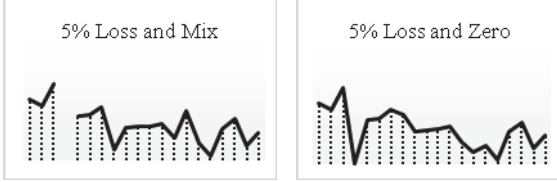


Fig. 13. Case b) and Case c) Zero

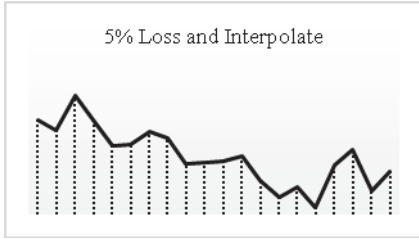


Fig. 14. Case c) 5% Loss and Interpolation

Table 2

Streaming volatile data results

Experiment	$r_{XY}$
5% data lost	73%
5% data lost and 5% data mixed	53%
5% data lost and replaced with Zero	95%
5% data lost and Interpolation	90%

As we could see from simulation, package sequences may significantly increase data quality for IoT communications. Specifically, this behaviour is useful for short-lived sessions when we would like to send only important most valuable information to the server. DCCP protocol mentioned above were designed to support VoIP communications and have already implemented majority of functionality, however it is not supported by application level protocols like CoAP, MQTT-SN etc, could not transmit compressed data as shown above and it could not be used for communication with SMS message as a transport.

### Protocol reference qualities

As a result of detailed analysis on existing approaches and solutions available on the market we decided to select below criteria for computing **reference qualities** for the desired protocol:

1. Transport unaware with possible values 1 or 0.
2. Minimum data exchange measured by count of system data send with data post request.
3. Open licence (protocol requiring royalty payments are not optimal due to the price) with possible values 1 or 0.

4. Service discovery. Friendly model of identification of user\device. End-user device should be able to authorize by serial number as a username. Preferably no limits in selection of a username identifier. Possible values 0, 0.5 or 1.

5. Ability to use GSM Alphabet [19] without extra work.

Decision were made to use taksonometric methodology for investigation with possible values 0, 0.5 or 1. First of all we should build criteria matrix, with exclusion for header size, where we pick exact value for most common SEND request.

$$X = \begin{Bmatrix} x_{11} & x_{1j} & x_{1m} \\ \dots & \dots & \dots \\ x_{i1} & x_{ij} & x_{in} \\ \dots & \dots & \dots \\ x_{m1} & x_{mj} & x_{mn} \end{Bmatrix}, \quad (2)$$

where  $i...n$  – criteria number;

$j...m$  – protocol number.

Given that CoAP – 1, MQTT-SN – 2, XMPP – 3, STOMP – 4 we could build matrix of protocol qualities:

$$X = \begin{Bmatrix} 0_{11} & 68_{12} & 1_{13} & 1_{14} & 1_{15} \\ 1_{12} & 17_{22} & 1_{23} & 1_{24} & .5_{25} \\ 0_{31} & 68_{32} & 1_{33} & .5_{34} & 0_{35} \\ 1_{41} & 34_{42} & 1_{43} & 1_{44} & 1_{45} \end{Bmatrix}. \quad (3)$$

After that we could compute normalized matrix Z:

$$Z = \begin{Bmatrix} z_{11} & z_{1j} & z_{1m} \\ \dots & \dots & \dots \\ z_{i1} & z_{ij} & z_{in} \\ \dots & \dots & \dots \\ z_{m1} & z_{mj} & z_{mn} \end{Bmatrix}; \quad (4)$$

$$z_{ij} = \frac{x_{ij} - \overline{x_{i*}}}{\sigma_{i*}}; \quad (5)$$

$$\overline{x_{j*}} = \frac{1}{m} \sum_{i=1}^n x_{ij}; \quad (6)$$

$$\sigma_{j*}^2 = \frac{1}{m} \sum_{i=1}^n (x_{ij} - \overline{x_{j*}})^2; \quad (7)$$

$$Z = \begin{Bmatrix} -1_{11} & .96_{12} & 0_{13} & .57_{14} & .9_{15} \\ 1_{12} & -1.34_{22} & 0_{23} & .57_{24} & -.3_{25} \\ -1_{31} & .96_{32} & 0_{33} & -1.33_{34} & -1.5_{35} \\ 1_{41} & -.57_{42} & 0_{43} & .57_{44} & .9_{45} \end{Bmatrix}. \quad (8)$$

With that we could finally compute reference qualities vector and quasi distances vector:

$$R_j = \sum_{i=1}^n (z_{ij} - z_i^{\xi})^2; \quad (9)$$



$$z_*^f = \begin{Bmatrix} 1 \\ -1.34 \\ 0 \\ .57 \\ .9 \end{Bmatrix}, R_j = \begin{Bmatrix} 9.33_{COAP} \\ 1.45_{MQTT-SN} \\ 20.48_{XMPP} \\ 0.59_{STOMP} \end{Bmatrix}. \quad (10)$$

On Fig. 15 we represent graphically quasi distance to the most optimal protocol.

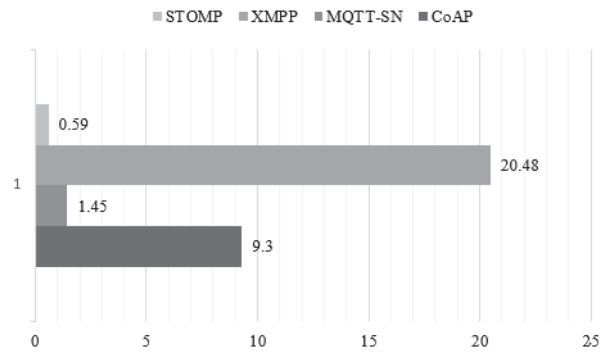


Fig. 15. Protocol comparison

### Renovation vs Innovation

Major ways of a software modernization have been outlined in [20]. We decide to use applicable part out of them for decision making. (excluding *Freeze* and *Outsource* as not relevant)

**Discard:** throw all the software away and start again from scratch. This removes the legacy problem ‘at a stroke’, but also removes a useful source of information for defining the requirements of the new system. However, much of the system may be stable, thoroughly debugged, and a useful asset.

**Wrap:** recently, much interest has been shown in ‘wrapping’ legacy systems, or parts of them, in object type wrappers. The interfaces to the legacy software are identified, and then encapsulated by an object which replaces the interface to the caller.

**Carry on:** Despite all the problems of support, the organization decides to carry on maintaining for another period.

**Reverse engineering:** However casual or formal, the process of maintaining a large software system is basically request-driven, and involves the following steps:

(i) understanding the current software, including translating the requested behavioral change into a change to the software

(ii) modification of the software. It is crucial that no unforeseen changes are made, so impact analysis is essential

(iii) revalidation of the software.

As we outlined above M2M regular communication solution consist from transport layer (OSI Level 3) and application layer (OSI Level 4 or higher). First of all we limit options for evaluation based on previous assessment results:

- (i) architecture and conceptual design overview
- (ii) quasi distance from best suite approach

Table 3

#### Transport Layer

Protocol	Message	Decision
TCP	If reliability is necessary and possible could be used as is	Carry On
UDP	Could be used unless application layer provide QoS (message sequences)	Carry On
DCPP	Could not be used due to lack of support for Windows and Mac. Unless UDP could be enriched with QoS is not necessary.	Reverse Engineering Sequence feature
SMS	Could be used as is, require support from application layer protocol	Wrap

Table 4

#### Application Layer

Protocol	Conclusion	Decision
CoAP	Good architecture for distributed system. Service bus support. Huge overhead on message size	Reverse Engineering/ Wrap
XMPP	Lack support of GSM Alphabet	Discard
STOMP	Complex architecture. HTTP is a transport	Discard
MQTT-SN	Do not allow changes after v3.1, is not able to support our needs	Discard

Table 5

#### Approaches decomposition

Approach	Description
CoAP Reverse Engineering	CoAP already have majority of functions, by extending its functionality and specification the goal could be achieved.
CoAP Wrap	Design a new protocol, which will use CoAP as a transport layer. The message of a new protocol becoming a payload for CoAP
Alternatively	Start creating brand new protocol

Based on the results for [21] for decision model framework we selected RENESIANSE Framework [22], as a baseline to do a final decision on action to be taken. RENESIANSE state that technology that supports evolutionary systems must enable

(i) the creation of systems that are designed to evolve, and

(ii) the transformation of today's legacy systems into evolvable systems.

This by all means should be interpreted as not trying to change something that is already working in an expected fashion but instead do an enrichment where it is necessary and maintain evolutionary updates to your enrichment as far as system keep changing. On this basis we could select option "Wrap" as a most efficient and creating a new application level protocol which will be based on CoAP for UDP and TCP with adding missing feature from DCCP (message sequences), as well as has an extension to support SMS as a transport layer. If we get back to our initial assessment of reference qualities, we will see that using CoAP with combination of new protocol providing necessary functionality will give is best possible rank.

## Conclusion

Most popular application level protocols for M2M communication where investigated as well as possible transport that could be used. Simulation on sending

messages through non-reliable connection was performed. Simulation show that for IoT services losing some packets might be acceptable unless packet sequence is known. Reference qualities, functional and non-functional requirements for M2M protocol was build. Research have demonstrated that none of the existing protocols fully support IoE (IoT) networks requirements in a low bandwidth network. RENESIANSE Framework was used to make a decision across multiple options for extensibility task. An innovation versus renovation trade-off analysis was performed in order to select relevant actions to improve existing state. Analysis show that DCCP protocol should be used as a baseline for message sequence feature design. Decision making framework show that inventing a new protocol capable to reuse BS CoAP is the most suitable approach.

In future works we are going to develop specification for new protocol as well as prototype and estimate QoS. Another direction of communication improvement should be detailed analysis of compressed data exchange and the ways to reduce number of packets involved.

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### ЭТАЛОННЫЕ АТРИБУТЫ КАЧЕСТВА М2М ПРОТОКОЛЫ КОМУНИКАЦІЇ В МЕРЕЖАХ З НИЗЬКОЮ ПРОПУСКНОЮ ЗДАТНІСТЮ

М.Г. Бражиненко, В.Л. Шевченко, В.Я. Петрівський

Еволюція Інтернету досі була чотирьохетапним процесом. Вона розпочалась з базового підключення, потім еволюціонувала до мережевої економіки, потім перейшла до іммерсивного досвіду і тепер знаходиться на четвертому етапі - ІоЕ (Інтернет всього). Інтернет всього не є відчутним терміном. Швидше, саме зв'язки між людьми, процесами, даними і речами створюють цінніший і актуальніший досвід, перетворюючи інформацію на дії, які створюють нові здатності і безпрецедентні економічні можливості. Старіння суспільства є однією з причин, по яким ІоЕ необхідно, надаючи можливість людям жити самотньо, без сторонньої допомоги, довше. ІоЕ виходить за межі традиційної М2М (машина – машина) взаємодії, технологій та проколів. Незважаючи на це найбільшим обмеженням усіх існуючих платформ та технологій є їхня взаємна сумісність. В даній роботі ми розглянули найпопулярніші протоколи взаємодії, що здатні реалізовувати філософію і цінності ІоЕ в їх поточному стані. Порівняли їх можливості, специфіку імплементації, обмеження та області застосування. Визначили теоретичну можливість практичного застосування в мережах з низькою пропускною здатністю. З метою визначення прихованого потенціалу кожного із запропонованих рішень ми змоделювали поведінку системи в мережі з низькою пропускною здатністю у різних ситуаціях, визначили найкращі з урахуванням специфіка області застосування а також можливість підтримки обраних сценаріїв різними протоколами. Як результат порівняння визначили квазі відстані до найкращого. На підставі отриманих даних визначили критерії та ключові вимоги для протоколу взаємодії. Порівняння продемонструвало що викростання створення нового протоколу на базі СОАР для з'єднання по мережі інтернет, з додаванням можливості визначати порядок повідомлень (пакетів), а також з можливістю передачі даних за допомогою SMS у якості транспорту і здатністю змінювати поведінку QoS модуля в залежності від області застосування має вирішити поточну технологічну проблему.

**Ключові слова:** надзвичайна ситуація, моніторинг, публікація, підписка, протокол, raspberry PI.

### ЭТАЛОННЫЕ АТРИБУТЫ КАЧЕСТВА М2М ПРОТОКОЛОВ КОММУНИКАЦИИ В СЕТЯХ С НИЗКОЙ ПРОПУСКНОЙ СПОСОБНОСТЬЮ

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Эволюция Интернета до сих пор была четырехэтапным процессом. Все началось с базового подключения, затем перешло к сетевой экономике, затем иммерсивному опыту и теперь находится на четвертом этапе - ІоЕ (Интернет всего). Интернет всего не является осязаемым термином. Скорее, именно связи между людьми, процессами, данными и вещами создают более ценный и актуальный опыт, превращая информацию в действия, которые создают новые возможности и беспрецедентные экономические возможности. Старение общества является одной из причин, по которым ІоЕ необходимо, чтобы люди жили дольше без посторонней помощи. В данной работе мы разработали спецификацию (критерии) для нового протокола взаимодействия.

**Ключевые слова:** чрезвычайная ситуация, мониторинг, публикация, подписка, протокол, raspberry PI.