Selection of Mobile IoT Technologies for Long Range (communication) based on TOPSIS Method with Ideal Optimization Solution

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Abstract : In today's era is covered by the technology and IoT is play vital role for communication over network. Also the transmission of data over network required the sensors that sends data in every interval of time. So type of communication will always takes the best solution that sends the data without any interrupt and perform the smooth communication over the network. Basically Long-range IoT wireless technologies form the basis for a low power wide area network (LPWAN) used for this communication. This paper proposed the some LPWAN technologies LTE-M, LoRa and Sigfox. This paper considered some of comparative parameters like bandwidth, Security, range, Allow private network, localization etc. But while choosing the technologies it is hard to difficult. So, taking the expert review from the five expertise and depending on the parameter give the priority to criteria. In these types of networks, end devices with low energy consumption typically sensors are connected to gateways that transmit data to other devices and network servers. The network devices assess the received data and control the end devices. Accordingly, the protocols are specially designed for long-range capabilities, low-power devices, and reduced operating costs.

***IndexTerms* - LPWAN technologies and standards, Multi-Criteria Decision Analysis (MCDA), Decision making system, Ideal optimization Solution, Negative Ideal Solution.**

I. Introduction

1. LPWAN Technologies(IoT Connectivity)

For a long time, cellular wireless technologies have had a monopoly position in long-range applications that can connect a device directly to the Internet without a gateway. Thanks to the well-established infrastructure of base stations worldwide, end products only require a SIM card to communicate with the cloud. After successful initialization and registration with the network provider, data can be sent and received.[9]

Further development of cellular wireless technologies in the past generally focused on increasing data transmission rates. LTE Advanced, for instance, now enables a transmission rate of up to 3.9 Gbps in the downlink and 1.5 Gbps in the uplink. However, most things in the IoT do not transmit such huge amounts of data (the majority of them require less than 100 bpm) and higher data rates result in higher power consumption for end devices. The focus of successful communication technology is therefore on long ranges, reliable communication, and low power consumption for extended battery life.[9]

There are many LPWAN technologies and standards, This paper mainly focused on SigFox, LoRa, and LTE-M, because these technologies are considered as active development and deployment. LTE-M and Narrowband-IoT (also called “NB-IoT”) have recently emerged as new technologies in market era.

LTE-M : LTE-M and Narrowband-IoT (NB-IoT) are promising additions to the LPWAN space. LTE-M is Third Generation Partnership Project’s (commonly known as “3GPP”) response to intense interest in LPWAN solutions that uses with an standard LTE connectivity. NB-IoT is another 3GPP construct challenging the disruption Sigfox and LoRa Alliance ignited, however, NB-IoT is different from LTE-M in that it operates *outside* of the LTE construct.

LoRa

LoRaWAN is a media access control (MAC) protocol for wide area networks. It is designed to allow low-powered devices to communicate with Internet-connected applications over long range wireless connections. LoRaWAN can be mapped to the second and third layer of the OSI model. It is implemented on top of LoRa or FSK modulation in industrial, scientific and medical (ISM) radio bands.

SigFox

SigFox uses proprietary technology, an example of using a slow modulation rate to achieve a more extended range. Due to this design choice, SigFox is an excellent option for applications where the system only needs to send small, infrequent bursts of data.

2. Basic Framework for LPWAN Technologies

The selection of any technologies will be based on certain criteria which satified the all requirements of data over network.

To select any technologies requires the aim and goal for work completion and hence the different critria will be focused during the selection of any technologies.

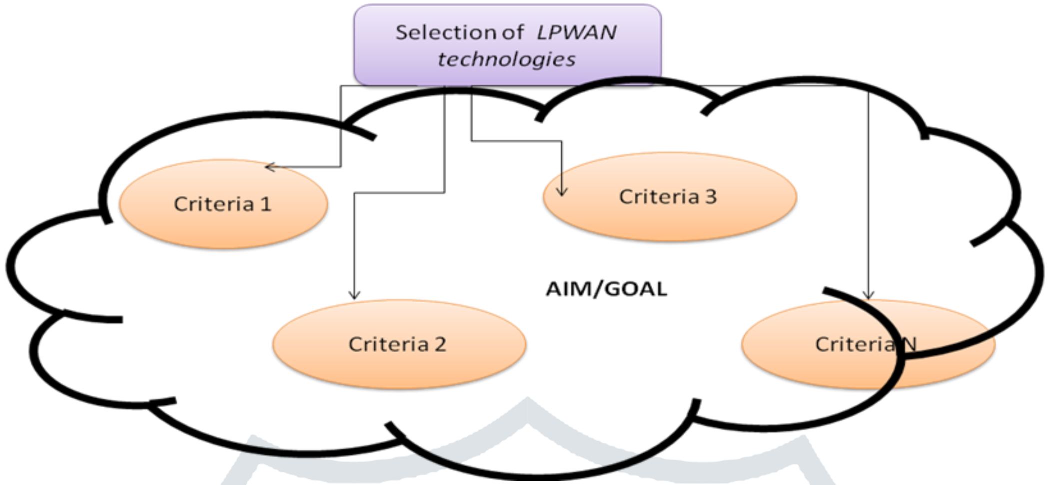

Figure 2.1: A Framework for selection criteria of LPWAN technologies

3. Comparative table for LTE-M, LoRa and Sigfox

In every LPWAN technologies is based on certain criteria and its modulation and the following table shows the different modulation for LTE-M ,LoRa, Sigfox that satisfies the work of any communication.

Modulation	LTE-M	LoRa	Sigfox
Frequency	Licensed LTE frequency bands	Unlicensed ISM bands (868 MHz in Europe, 915 MHz in North America, and 433 MHz in Asia)	Unlicensed ISM bands (868 MHz in Europe, 915 MHz in North America, and 433 MHz in Asia)
Bandwidth	200 kHz	250 kHz and 125 kHz	100 Hz
Maximum data rate	200 kbps	50 kbps	100 bps
Bidirectional	Yes / Half-duplex	Yes / Half-duplex	Limited / Half-duplex
Maximum payload length	1600 bytes	243 bytes	12 bytes (UL), 8 bytes (DL)
Range	1 km (urban), 10 km (rural)	5 km (urban), 20 km (rural)	10 km (urban), 40 km (rural)
Authentication & encryption	Yes (LTE encryption)	Yes (AES 128b)	Not supported
Localization	No (under specification)	Yes (TDOA)	Yes (RSSI)
Allow private network	No	Yes	No
Standardization	3GPP	LoRa-Alliance	Sigfox company is collaborating with ETSI on the standardization of Sigfox-based network

Table 2.1: Comparative Parameters [10]

II. Multi-Criteria Decision Analysis (MCDA).

Multiple-Criteria Decision Analysis (MCDA) is a operations research that explicitly used and considers the multiple criteria for any discipline in decision-making environments. MCDA for supporting strategic decision making, particularly within strategy workshops [1]. In Daily social and professional life here are many such situation founds where user need to be evaluated in making decisions [4].

There are some problem solving techniques are:

- TOPSIS (Technique for Order Preference by Similarity to the Ideal Solution)
- SAW (Simple Additive Weighting)
- ANP (Analytic network process)
- AHP (The Analytical Hierarchy Process)
- SMART (The Simple Multi Attribute Rating Technique)

From above solving techniques we consider TOPSIS method to find out Ideal Solution for Order Preference for selection of Web Development Language.

Multi-Criteria Decision Analysis (MCDA), a methodology for supporting decision making for selection of Application when multiple objectives have to be achieved [4,5]. The AHP first decomposes the decision problems into sub problems. Then the decision-maker method evaluates pair wise comparisons with the relative importance of its various considerations. The AHP converts these evaluations based on the numerical values of weights or priorities, which are used to calculate a score for each alternatives. A consistency index measures the extent to which the decision-maker has been consistent in her responses.

III. LPWAN Technologies Uses

LTE-M: Long term Evolution for Machines[11]

- LTE-M is the abbreviation for LTE Cat-M1 or Long Term Evolution (4G), category M1. This technology is used without a gateway and on batteries.
- It's cheaper. Devices can connect to 4G networks with chips that are less expensive to make, because they are half-duplex and have a narrower bandwidth.
- Long Battery Life. Devices can enter a "deep sleep" mode called Power Savings Mode (PSM) or wake up only periodically while connected. That mode is called extended discontinuous reception (eDRX).
- Service Costs Less. Because the maximum data rate of LTE-M devices is only about 100 kbits/s, Carriers can offer service plans that closer to old 2G M2M pricing than 4G pricing

LoRa[12]

- End Device, Node, Mote - object with an embedded low-power communication device.
- Gateway - Antennas that receive broadcasts from End Devices and send data back to End Devices.
- Network Server - Servers that route messages from End Devices to the right Application, and back.
- Application - A piece of software, running on a server.
- Uplink Message - A message from a Device to an Application.
- Downlink Message - A message from an Application to a Device.

Sigfox[09]

SigFox is a tailor-made solution for long ranges (30-50 km in rural areas, 3-10 km in urban areas), low data rates (12 bytes per message, max. 140 messages a day per end device), and preferably low power operation. SigFox uses the sub-GHz band (868 MHz in Europe) and employs BPSK modulation with ultra-narrowband technology. End devices equipped with SigFox technology transmit data to SigFox base stations, which then forward the data to SigFox cloud servers. This is where the data are processed before the results are sent back to the respective end devices for visualization.

IV. Features of LPWAN technologies

Every LPWAN technologies and standards is having some criteria for selection. Following are the LPWAN technologies selection process which is considers in DMCAA method.

- Frequency (A1):
- Bandwidth (A2):
- Maximum Data Rate (A3):
- Payload Length (A4):
- Range (A5):
- Authentication & Security (A6):
- Localization (A7):
- Bidirectional (A8):
- Allow Private N/W (A9):
- Recommendation (A10):

V. Method overview on TOPSIS with LPWAN technologies selection

LPWAN technologies and standards comes in various different guises. The basic system is the similar, but the look and feel and the subsystems around it are different. Each application version is produced and developed by an different organizations with its own aims and objectives. The result is a unique LPWAN technologies and standards which is aimed at a slightly different set of users.

Following Table shows the different LPWAN technologies and standards with their purposes..

Technologies	Purpose of technologies
LTE-M	Evolve an existing technology to make more money for network operators
LoRa	Provide a technology that lets other companies enable a global Internet of Things
Sigfox	Become a global Internet of Things operato

Table 5.1 : Different LPWAN technologies and standards with their aim sand purpose

For consideration of LPWAN technologies and standards we select five applications of estimates relative importance of criteria based on rating scale. Now following table is shows the relation of criteria with weight LPWAN technologies Important term is related to TOPSIS is Weights.

Sr. No	Criteria	Weight as per Highest Priority	Rating Scale
1	Frequency (A1)	4	10 High-1 Low
2	Bandwidth (A2)	8	10 Hign-1 Low
3	Maximum Data Rate (A3)	5	10 High-1 Low
4	Payload Length (A4)	7	10 High-1 Low
5	Range (A5)	9	10 High-1 Low
6	Authentication & Security (A6)	10	10 High-1 Low
7	Localization (A7)	6	10 High-1 Low
8	Bidirectional (A8)	1	10 High-1 Low
9	Allow Private N/W (A9)	2	10 High-1 Low
10	Recommendation (A10)	3	10 High-1 Low

Table 5.2 : Relation of Criteria with Weight as per Highest Priority

The first Basic step to take weight for each mobile application and calculate Attribute weight as per table shown. Following table that is used to objectively make decision from a range of options for making selection.

LTE-M

Sr. No	**Criteria**	**Decision Maker for LTE-M**					**Attribute Weight**	**Total**
	Reference	Expert 1	Expert 2	Expert 3	Expert 4	Expert 5		
1	A1	7	6	7	8	6	(7+6+7+8+6)/5	6.8
2	A2	6	6	7	6	7	(6+6+7+6+7)/5	6.4
3	A3	8	7	6	6	5	(8+7+6+6+5)/5	6.4
4	A4	7	6	7	8	7	(7+6+7+8+7)/5	7
5	A5	9	8	7	6	7	(9+8+7+6+7)/5	7.4
6	A6	9	9	9	8	8	(9+9+9+8+8)/5	8.6
7	A7	8	7	6	7	6	(8+7+6+7+6)/5	6.8
8	A8	7	8	5	7	7	(7+8+5+7+7)/5	6.8
9	A9	7	7	6	6	7	(7+7+6+6+7)/5	6.6
10	A10	7	6	7	8	7	(7+6+7+8+7)/5	7

Table 5.3 Decision Maker table for LTE-M

The total of Criteria is calculated by the average of all experts weight.
S(LTE-M)= LTE-M (E) ……………………..(1)
[LTE-M (E)= ∑ (E1+E2+E3+E4+E5)/5]
Following table that is used to objectively make decision from a range of options for making selection.

LoRa

Sr. No	**Criteria**	**Decision Maker for LoRa**					**Attribute Weight**	**Total**
	Reference	Expert 1	Expert 2	Expert 3	Expert 4	Expert 5		
1	A1	7	7	6	7	7	(7+7+6+7+7)/5	6.8
2	A2	7	6	7	6	6	(7+6+7+6+6)/5	6.4
3	A3	7	7	6	6	5	(7+7+6+6+5)/5	6.2
4	A4	6	6	7	7	8	(6+6+7+7+8)/5	6.8
5	A5	8	8	7	8	7	(8+8+7+7+7)/5	7.6
6	A6	7	7	7	6	6	(7+7+7+6+6)/5	6.6
7	A7	7	8	6	7	7	(7+8+6+7+7)/5	7
8	A8	6	7	6	6	8	(6+7+6+6+8)/5	6.6
9	A9	5	7	6	6	5	(5+7+6+6+5)/5	5.8
10	A10	7	6	6	7	7	(7+6+6+7+7)/5	6.6

Table 5.4 Decision Maker table for LoRa

S(LoRa)= LoRa (E)…………………………..(2)
Following table that is used to objectively make decision from a range of options for making selection.

Sigfox

Sr. No	**Criteria**	**Decision Maker for Sigfox**					**Attribute Weight**	**Total**
	Reference	Expert 1	Expert 2	Expert 3	Expert 4	Expert 5		
1	A1	8	7	8	7	6	(8+7+8+7+6)/5	7.2
2	A2	7	8	7	8	7	(7+8+7+8+7)/5	7.4
3	A3	8	7	8	6	6	(8+7+8+6+6)/5	7
4	A4	7	7	7	7	8	(7+7+7+7+8)/5	7.2
5	A5	8	7	8	7	7	(8+7+8+7+7)/5	7.4
6	A6	8	8	7	8	8	(8+8+7+8+8)/5	7.8
7	A7	7	7	7	7	6	(7+7+7+7+6)/5	6.8
8	A8	8	7	6	7	7	(8+7+6+7+7)/5	7
9	A9	7	8	6	8	7	(7+8+6+8+7)/5	7.2
10	A10	6	7	7	7	6	(6+7+7+7+6)/5	6.6

Table 5.5 Decision Maker table for Sigfox

S(Sigfox)= Sigfox (E)…………………………..(3)
A Following table that is used to objectively make decision about making selection from a range of options.

VI. Techniques for Order Preference by Similarity to obtained the Ideal Solution

These method process two artificial alternatives are hypothesized:

i. **Ideal alternative:** One which has the best attributes values (i.e. max. benefit attributes and min. cost attributes)

ii. **Negative ideal alternative:** One which has the worst attributes values. (i.e. min. benefit attributes and max. cost attributes)

VI. Result of TOPSIS for LPWAN

TOPSIS selects the alternative that is the closest to the ideal solution and farthest from negative ideal solution. The following Steps involved

First Step – Standardize the decision matrix.

In standardize the decision matrix method transforms various attribute dimensions into non-dimensional attributes, which is allows comparisons across criteria of LPWAN. For standardizing, each column of Decision Matrix is divided by root of sum of square of respective columns. From the above equation 1,2,3,4 and 5.

Total Attribute is calculated by the square root of all decision Matrix

Total Attribute Weight (TAW)= $\sqrt{S(LTE\text{-}M)^2+S(LoRa)^2+S(Sigfox)^2}$ **……..(4)**

Sr. No	**Criteria**	**Attribute Weight**			TAW	
	Reference	LTE-M S(LTE-M)	LoRa S(LoRa)	Sigfox S(Sigfox)		TAW
1	A1	6.8	6.8	7.2	$\sqrt{6.8^2+6.8^2+7.2^2}$	12.01332593
2	A2	6.4	6.4	7.4	$\sqrt{6.4^2+6.4^2+7.4^2}$	11.6910222
3	A3	6.4	6.4	7	$\sqrt{6.4^2+6.2^2+7^2}$	11.44202779
4	A4	7	7	7.2	$\sqrt{7^2+6.8^2+7.2^2}$	12.240915
5	A5	7.4	7.4	7.4	$\sqrt{7.4^2+7.6^2+7.4^2}$	12.81717598
6	A6	8.6	8.6	7.8	$\sqrt{8.6^2+6.6^2+7.8^2}$	14.44852934
7	A7	6.8	6.8	6.8	$\sqrt{6.8^2+7^2+6.8^2}$	11.77794549
8	A8	6.8	6.8	7	$\sqrt{6.8^2+6.6^2+7^2}$	11.89453656
9	A9	6.6	6.6	7.2	$\sqrt{6.6^2+5.8^2+7.2^2}$	11.78812962
10	A10	7	7	6.6	$\sqrt{7^2+6.6^2+6.6^2}$	11.89789897

Table 6.1 (A) Decision matrix table with Total Attribute Weight (TAW)

The standardized decision matrix is calculated by

SDM=S(LTE-M)/TAW & S(LoRa)/TAW & S(Sigfox)/TAW …………………………(5)

Sr. No	**Criteria**	**Total**			
	Reference	LTE-M S(LTE-M)	LoRa S(LoRa)	Sigfox S(Sigfox)	TAW
1	A1	6.8/12.01	6.8/12.01	7.2/12.01	12.01
2	A2	6.4/11.69	6.4/11.69	7.4/11.69	11.69
3	A3	6.4/11.44	6.4/11.44	7/11.44	11.44
4	A4	7/12.24	7/12.24	7.2/12.24	12.24
5	A5	7.4/12.81	7.4/12.81	7.4/12.81	12.82
6	A6	8.6/14.44	8.6/14.44	7.8/14.44	14.45
7	A7	6.8/11.78	6.8/11.78	6.8/11.78	11.78
8	A8	6.8/11.89	6.8/11.89	7/11.89	11.89
9	A9	6.6/11.78	6.6/11.78	7.2/11.78	11.79
10	A10	7/11.89	7/11.89	6.6/11.89	11.90

Table 6.1 (B) Standardize the decision matrix

From table 6.1(B) values are

Sr. No	Criteria	Total			
	Reference	LTE-M	LoRa	Sigfox	TAW
		S(LTE-M)	S(LoRa)	S(Sigfox)	
1	A1	0.57	0.57	0.60	12.01
2	A2	0.55	0.55	0.63	11.69
3	A3	0.56	0.56	0.61	11.44
4	A4	0.57	0.57	0.59	12.24
5	A5	0.58	0.58	0.58	12.82
6	A6	0.60	0.60	0.54	14.45
7	A7	0.58	0.58	0.58	11.78
8	A8	0.57	0.57	0.59	11.89
9	A9	0.56	0.56	0.61	11.79
10	A10	0.59	0.59	0.55	11.90

Table 6.1 (C) Standardize the decision matrix Value

Second Step – Now, Construct weighted standardized decision matrix (WSD) by multiplying attributes weight to each rating. From Table 2 & 6.1(c)

Sr. No.	Criteria	Attribute Rate	Total			
	Reference		LTE-M	LoRa	Sigfox	TAW
			S(LTE-M)	S(LoRa)	S(Sigfox)	
1	A1	4	0.57	0.57	0.60	12.01
2	A2	8	0.55	0.55	0.63	11.69
3	A3	5	0.56	0.56	0.61	11.44
4	A4	7	0.57	0.57	0.59	12.24
5	A5	9	0.58	0.58	0.58	12.82
6	A6	10	0.60	0.60	0.54	14.45
7	A7	6	0.58	0.58	0.58	11.78
8	A8	1	0.57	0.57	0.59	11.89
9	A9	2	0.56	0.56	0.61	11.79
10	A10	3	0.59	0.59	0.55	11.90

Table 6.2 standardize the decision matrix

From table 6.2 **Weighted Standardized decision matrix is calculated**
WSDM=AW*SDM ……………….(6)
Where AW-Attribute weight; SDM- Standardized Decision Matrix

Third Step – Determine **ideal solution** and **negative ideal solution**

Sr. No	Criteria	Attribute	Total				
	Reference	Rate	LTE-M	LoRa	Sigfox	Max Value for Ideal Solution	Min Value for Negative Ideal Solution
			S(LTE-M)	S(LoRa)	S(Sigfox)		
1	A1	4	2.26	2.26	2.40	2.4	2.26
2	A2	8	4.38	4.38	5.06	5.06	4.38
3	A3	5	2.80	2.80	3.06	3.06	2.8
4	A4	7	4.00	4.00	4.12	4.12	4
5	A5	9	5.20	5.20	5.20	5.2	5.2
6	A6	10	5.95	5.95	5.40	5.95	5.4
7	A7	6	3.46	3.46	3.46	3.46	3.46
8	A8	1	0.57	0.57	0.59	0.59	0.57
9	A9	2	1.12	1.12	1.22	1.22	1.12
10	A10	3	1.77	1.77	1.66	1.77	1.66

Table 6.3 Weighted standardize the decision matrix table

A set of maximum values for each criteria is **Ideal solution**.
Idle solution={2.4,5.06,3.06,4.12,5.2,5.95,3.46,0.59,1.22,1.77}
A set of minimum values for each criteria is **Negative Ideal solution**
Negative Idle Solution = {2.26,4.38,2.8,4,5.2,5.4,3.46,0.57,1.12,1.66}
Fourth Step – Determine separation from **ideal solution.** **S_i*** and Si'
Si*= ∑ WSDC(LTE-M) & ∑ WSDC(LoRa) & ∑ WSDC(Sigfix) ………..(7)
Si'= ∑ WSDC(LTE-M) & ∑ WSDC(LoRa) ∑ WSDC(Sigfix)………(8)

Sr. No	Criteria	Ideal Solution Si*			Criteria	Negative Ideal solution Si'		
		LTE-M	LoRa	Sigfox		LTE-M	LoRa	Sigfox
1	**A1**	0.136	0.136	0.003	**A1**	-0.004	-0.004	-0.137
2	**A2**	0.681	0.681	-0.004	**A2**	0.001	0.001	-0.684
3	**A3**	0.263	0.263	0.001	**A3**	0.003	0.003	-0.259
4	**A4**	0.117	0.117	0.003	**A4**	-0.003	-0.003	-0.117
5	**A5**	0.004	0.004	0.004	**A5**	0.004	0.004	0.004
6	**A6**	-0.002	-0.002	0.552	**A6**	-0.552	-0.552	0.002
7	**A7**	-0.004	-0.004	-0.004	**A7**	-0.004	-0.004	-0.004
8	**A8**	0.018	0.018	0.001	**A8**	-0.002	-0.002	-0.019
9	**A9**	0.100	0.100	-0.002	**A9**	0.000	0.000	-0.102
10	**A10**	0.005	0.005	0.106	**A10**	-0.105	-0.105	-0.004
	Si*	**1.318**	**1.318**	**0.660**	**Si'**	**-0.662**	**-0.662**	**-1.320**

Table 6.4 Ideal solution & Negative Ideal Solution

Fifth Step – Determine relative closeness to **ideal solution.**

SrNo	Criteria	Relative Closeness to Ideal Solution		
		LTE-M	LoRa	Sigfox
1	Si*	**1.318**	**1.318**	**0.660**
2	Si'	-0.66215298	-0.662153	-1.32025
3	**S_i*+S_i'**	0.656	0.656	-0.661
4	**S_i' /(S_i*+S_i')**	-1.00985056	-1.0098506	1.9988643

Table 6.5 Relative Closeness to Ideal Solution table

Best is Sigfox because the maximum relative closeness to ideal solution is 1.99.

VII. CONCLUSION

As per Experiment, TOPSIS method gives the Best solution 1.99 for SigFox Web Designing Language. So a user goes with Sigfox. If the any developer wants to select LPWAN technologies then TOPSIS helps for selecting best solution of among all.

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