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FELZMACS: A Novel Data Compression Model in Wireless Sensor Networks for Fast Data Transfer

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Abstract: Recent research on Wireless Sensor Networks has been multi-dimensional and exhaustive. Data compression is one area being focused, due to the reason that the data originated from the sensors and transmitted to the base station through intermediate entities require fast transmission. The data compression during the transmission effectively results in faster communication, node lifetime improvement as well slight protection of the data. The research on data compression encompasses various techniques proposed that include discrete cosine transform, run length encoding, embedded zero tree wavelet coding, and so on. It is well known that incorporating data compression into WSN further enhances energy efficiency. In this paper, a hybrid approach "Fast and Efficient Lempel Ziv Markov-Chain Adaptable Compression Scheme (FELZMACS)" involving two techniques namely Fast and efficient lossless adaptive compression scheme (FELACS) and Lempel Ziv Markov chain Algorithm (LZMA) methods are used for compressing the data each at a different level. The former approach is used to compress the data between the node and cluster head while the latter approach is used for data compression between the cluster head and the base station. The performance of this hybrid approach in terms of energy efficiency and delay is remarkable.

Keywords: *Data compression in wireless sensor networks, Hybrid approaches in data compression, fast transmission in wireless sensor networks, FELACS Compression, LZMA compression.*

1. Introduction:

Numerous potential applications of Wireless Sensor Networks (WSNs) that include precision agriculture, industrial applications, forest monitoring, military surveillance, health care and so on are now and then being deployed. [1]. The networks comprise several sensing devices which are geographically distributed which interact with the physical world and pass the information to the destinations. All the devices (sensor nodes as well base stations) are interconnected in a way that they cooperate and intend to perform higher-level sensing tasks. But the limitations in terms of bandwidth, energy, processing capability make the network resource constrained [2]. The prime factor in the energy consumption being the amount of data being transferred between the devices, if the number of bits could be reduced then the energy consumption becomes low. So as to reduce the data size, data compression could be one means in which the size of the data gets reduced with some technique.

There are several techniques that could be applied on various types of data like text, image, audio, video which would ultimately offer the compression. Data compression not only reduces the number of bits, but also it indirectly increases the lifetime of network. Moreover, the compression could result in data loss or no loss in data. The compression may be adaptive or non-adaptive, symmetric or asymmetric and so on. The taxonomy of Compression techniques is shown in figure 1. The techniques are broadly classified into three types namely data aggregation compression techniques, local data compression techniques and distributed data compression techniques.

• Data aggregation compression techniques: These techniques feature in extracting summaries such as mean values, maximum values and so on from the sensory data. The compression methods are further classified into tree structured, chain based and cluster based [3]. which are useful to certain application. Techniques such as PEGASIS, HEED, LEACH fall under this category.

• Local data compression techniques: Basing on the temporal correlation of the data, this type of compression takes place and could be text or image based. LZW, JPEG, DWT, DCT and other such algorithms fall under category. [4], [5], [6], [7]. Most popular techniques are under this category and useful for compression.

• Distributed data compression techniques: Those techniques which make use of high spatial similarities in the data collected from sensor nodes and compress, fall under this category. Few major techniques in this category include DSC, DTC, DSM. The techniques in

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this approach although conserves energy, but incur in information loss.

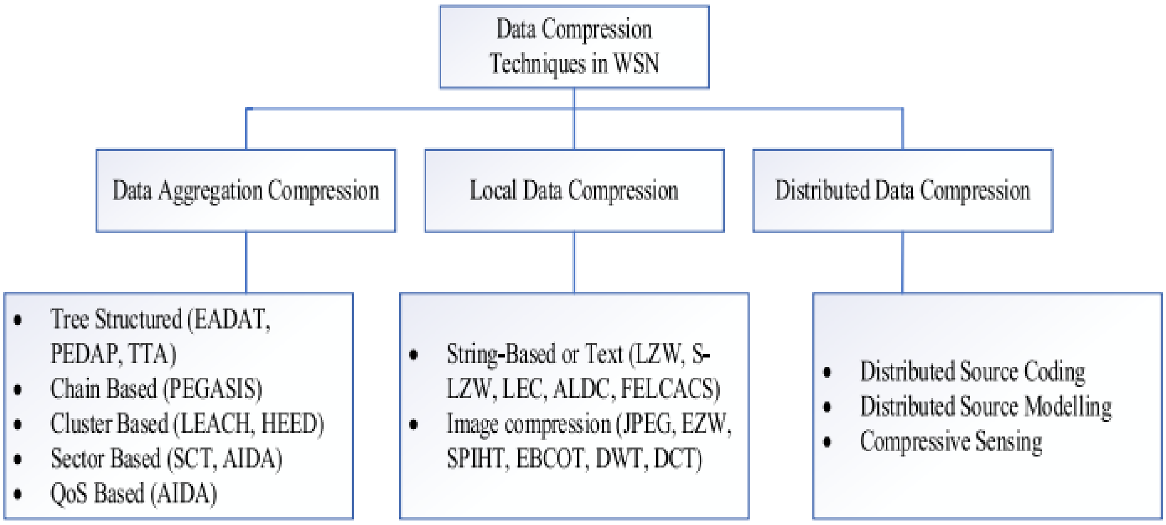

Fig 1: Various compression techniques [11]

Whichever may be the schemes, the factors to be considered while designing the compression scheme are as mentioned below.

Processing Complexity and memory requirements: The algorithms whichever designed for data compression must be simple so that they don't take much processing power, time and occupies less memory. The complexity in the design of algorithms consume more time and power which are the valuable resources in wireless sensor networks.

Data reduction during transmission: The data being transmitted must be kept minimal since both transmission & reception of bits consume power.

Reliability: The data compression schemes must be reliable so that there is no any missing of information.

Compression routing model: The mode of operation during the transmission must be planned in such a way that the intermediate nodes must handle the compression effectively.

Scalability: The algorithm must perform well despite the amount of data being compressed.

Security: Certain applications need security measures which demand for cryptographic algorithms to be implemented. The compression algorithms must be designed in such a way that there must not be any conflict with the security algorithms.

Robustness: As the applications are of wide variety, the respective compression technique/s must perform well and fulfil the requirements of the application.

Quality of Service (QoS): The compression algorithms must be chosen or the compression architecture must be well designed such that they do not hamper the quality-of-service parameters.

In this paper, the focus is on applying compression on the data being transmitted keeping in mind all the above-mentioned factors. Two algorithms are used as a part of designing the hybrid compression scheme. To do so the existing literature is studied and presented in the succeeding section. In the consecutive section the proposed methodology, implementation procedures and the results are presented. Finally, the conclusion is given in final section.

2. Literature Survey:

Zahraa Mazin et.al. [8] aimed at reducing the data representation and storage with which a method is developed that include LZW algorithm. The compression is based on the frequency of words and byte labelling which attained better compression ratio. In [9] Olli Väänänen et.al. performed their temporal compression algorithmic experiments subjected to LoRa based sensor node data to minimize the energy consumption. Although the simple approach LTC proposed by them was effective, it suffered from problems such as prediction latency, delay in compression of online data. Huffman compression is a widely used technique. Besides its simplicity it has own limitations and hence Ali et.al. [10] instead of using the conventional technique, cascade Huffman compression is used due to which the energy efficiency increased by 8%. Bose et.al. [11] performed a detailed survey and presented various methods in image compression. Mukesh Mishra et.al. in [12] claiming memory, energy and the speed of handling data to be constraints, devised a novel hybrid compression scheme by the name H-RLEAHE involving RLE and AHF. The results seems to be impressive.

Identifying the constraints in IoT nodes, Ammar Nasif et.al. [13] proposed a conceptual compression method applying deep learning concepts to adaptive Huffman algorithm and improved the performance in terms of compression ratio which could be very useful. However, the approach has some implementation challenges in IoT networks. Ketshabetswe et.al. [14] surveyed various data compression techniques and proposed a technique which focused on encoding the residues rather than the raw data so that the compression method proposed by them attained 87.5% coding efficiency and 70% energy savings. Chen et.al. [15] proposed a novel compression scheme Bayesian Predictive Coding which is the combination of Bayesian inference & Predictive coding methods and is lossy in nature. The technique involves sending only the error terms rather than the original signals ideating that the compression performance depends upon the prediction accuracy levels. Health care is a prime application area of wireless sensor networks in which lot of data is being generated and appropriate compression techniques would address memory and energy constraints. S. Kalaivani et.al. [16] proposed a hybrid compression approach (HCA) based on Rice Golomb coding which when implemented attained 70% savings in storage requirements. While N. Kimura et.al. [17] made a detailed study related to various compression and aggregation algorithms used in different wireless sensor networks applications.

Augusto Y. Horita et.al. [18] made their efforts in designing a novel scheme Lempel Ziv Markov Chain Algorithm (LZMA) using the Formal System Design (ForSyDe) [21] methodology. Their contribution is towards compressing the data in the avionic communication system. Their contribution is in accordance to the DO-178C [19] guidelines of Radio Technical Commission for Aeronautics and highly efficient. S. Kalaivani et.al. [22] proposed Modified Adaptive Rice Golomb Coding (MARGC) which was implemented using Sensor node NI 320 in wireshark. The performance was analyzed and compared with the Adaptive Huffman Coding in which the proposed technique offered better results.

Tong Chen et.al. [23] proposed a deep learning based CNN framework Deepcoder for video compression. Scalar quantization and Huffman codes are the techniques part of the framework. Their contribution offered better performance but other potential avenues such as GAN, RNN could be explored for further improving the framework. Ammar Yaseen Tuama et.al. [24] proposed a lossless cum dictionary-based compression algorithm which used two different datasets to demonstrate the compression technique. The algorithm exhibited superior performance in all means. S.Jancy et.al. [25] proposed a packet level data compression technique (PLDC) and compared the performance with their earlier technique. The proposed technique offered better performance in terms of compression ratio and time. Tarek Sheltami et.al. [26] reviewed various compression techniques among which two techniques namely Discrete Wavelet Transform (DWT) and Discrete Cosine Transform (DCT) were implemented using TinyOS. Peak Signal to Noise Ratio, Compression Ratio, throughput, End to End delay and battery lifetime are the metrics evaluated by inputting image data in which DWT offered better performance.

Jonathan Gana Kolo et.al. [27][28] proposed Fast and Efficient Lossless Adaptive Compression Scheme (FELACS) which gave an amazing performance in terms of memory and energy requirements. The algorithm works by implementing Golomb Rice Coding scheme on seven real world data sets which achieved a compression rate of 5.69 bits per sample and more than 55% energy savings. Also, the node's lifetime improvement happened by a factor of 2.22. Also the performance of FELACS is compared with S-LZW, LEC, mLEC, Simple-algorithm and ALDC in which the proposed technique outperformed the other major techniques.

In [29] Henry Ponti Medeiros et.al. performed lightweight compression using Huffman coding technique which performed well when compared with other algorithms. The researchers of [30] [31] performed a detailed study on data compression techniques and strategies applied on wireless sensor networks and portrayed their findings which are appreciable.

Rationality behind the chosen algorithms for our research work:

Having gone through the distinguished contributions of various researchers, it could be understood that compression plays a significant role in offering exceptional solutions that optimize energy, time and memory constraints. However, the best suited algorithm must be chosen for the intended application. As a part of our study two finest algorithms are chosen and combined into an efficient hybrid scheme so that the essential features could be derived. The hybrid approach aims at offering low compression rate, minimum transmission latency, low energy consumption. The hybrid algorithm is adaptive and lossless in nature.

The algorithms chosen are Fast and Efficient Lossless Adaptive Compression Scheme (FELACS) [28] and Lempel Ziv Markov Chain Algorithm (LZMA) [18]. Most of the algorithms offered good compression rate when they operate on the residues rather than the direct raw values. Golomb rice coding operates on residues which is used in the former algorithm. This data compression technique is operated on seven real time data sets and efficiently designed. It offered best performance when compared with other pretty good algorithms. The data in the wireless sensor networks could be of either form i.e., text, image, audio, video and so on. In our research we restricted our study to text, mostly to numeric data so that the residues shall be obtained and the algorithm could work on them. The proposed hybrid algorithm works in two phases. In the first phase the said technique shall be used for the data being transmitted from a Node to the Cluster Head.

During the second phase, the data gets transmitted from the cluster head to the base station. In this context the latter technique is used. Due to the predominant features of LZMA, it is considered as a CPU benchmark algorithm by the Standard Performance Evaluation Corporation (SPEC) [20]. Being a standard algorithm, it is thought that it suits our requirement and has been chosen as the second algorithm.

3. Proposed Work:

3.1 Architecture:

As a part of our proposed work in this research paper, various compression algorithms are studied among which FELACS [28] and LZMA [18] are chosen to be incorporated in the network model. Both the algorithms are integrated and a hybrid compression approach is planned to be implemented into our wireless sensor network model. The network model considered for the current implementation is same as our earlier contribution in which the network is clustered and the cluster head selection is done using GMM. The data compression is applied at two stages. One at the level where data from various sensor nodes getting transmitted to the cluster head and the other at the data being transmitted from cluster head to the sink node (base station).

Most WSNs send the sensing data among which the values are found to be nearby. To illustrate, in case of a temperature sensing node, the data values are around certain temperature. In FELACS the initial value is considered to be a reference value and the remaining values may be found to close to the reference value. Hence FELACS compression technique might best suit for compressing the data being transmitted from sensor nodes to cluster head.

LZMA was created as an LZ77 optimization, providing higher compression rate and fast decompression, with lower memory requirements which is modelled in three steps viz., Delta encoding, sliding dictionary encoding and Range encoding. Usually these encoding mechanisms are used in case of large amounts of data are to be compressed. The data from cluster heads to the base station comprises large quantities, using LZMA certainly reaps benefit during the second phase of transmission.

The integrated model "FELZMACS" which is a combination of FELACS and LZMA algorithms incorporated at various levels of data transmission is presented in figure 2.

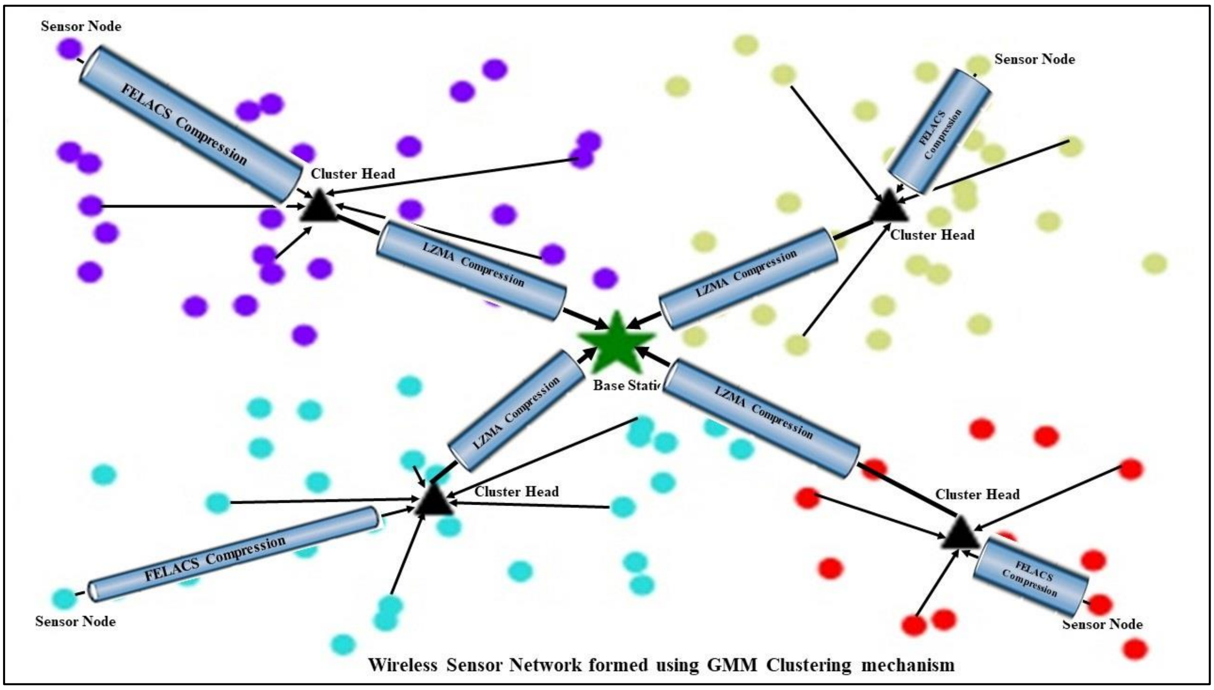

Fig 2: FELZMACS compression model incorporated into GMM-WSN

From the above figure it could be observed that from the sensor node the data being communicated to the cluster head is compressed using FELACS algorithm, while the data from cluster head is compressed with LZMA algorithm and transmitted to Base station.

The compression scheme FELZMACS is as given below.

The messages M_i to M_j within a time frame $t_e - t_s$ are to be transmitted from Node N_p to Base Station BS through Cluster Head CH_k. X_k is the concatenation of the mentioned messages which is done in the first step and passed to the FELACS compression algorithm. The algorithm compresses and transmits the output Y_k to the cluster head. In turn the compressed output is further compressed using LZMA algorithm and transmitted from the cluster head to the base station. The algorithms FELACS and LZMA are discussed below for a detailed understanding.

FELZMACS($M_i \ldots M_j$, N_p , CH_k, t_s,t_e)

{

$X_k \leftarrow \| M_i$

$Y_k \leftarrow FELACS_{N_p CH_k}(X_k)$

$Z_k \leftarrow LZMA_{CH_k BS}(Y_k)$

}

3.2 FELACS Compression:

FELACS is a block-based compression scheme proposed for WSNs, which is lossless and adaptive in nature. The technique is based on Golomb–Rice coding (GRC) method. In designing FELACS, few changes are done to original GRC. FELACS block diagram could be seen in figure 3.

1. To keep the overhead cost minimum, the choice of code options is limited to Golomb Rice 8 code family with k = 0, 1, 2...7).

2. To make the process more robust, the blocks are processed individually in which the first sample in a block is considered to be a reference sample, subsequently the residues of other samples are encoded.

3. A 3-bit binary code indicates the code option which is used for encoding.

4. To determine optimal k value, sum of the samples other than reference sample is used with which the method becomes fast and efficient. Only a maximum of 7 bit shift operations are required in determining the k value.

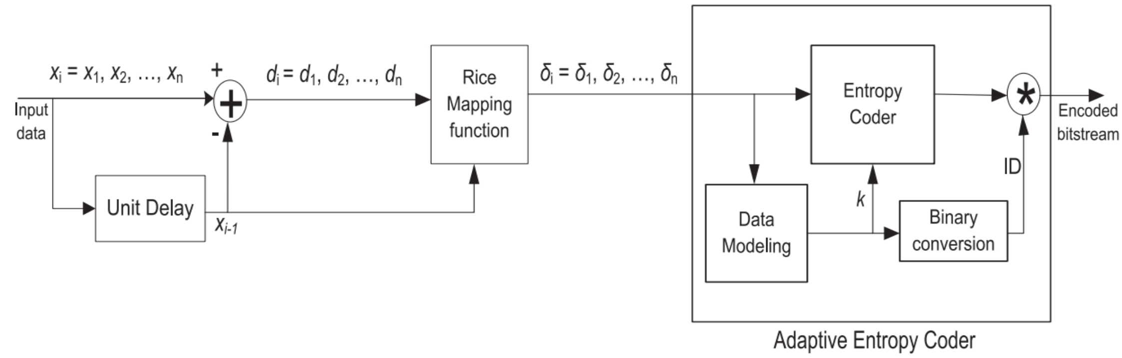

Fig 3: Block diagram of FELACS

The encoding and decoding processes of Golomb Rice coding are given below.

Encoding Process:

1. Reminder = Binary [Input & (Divisor - 1)]

2. Quotient =Unary (Input >> k)

3. Encoded data = {Quotient, Reminder}

Decoding Process:

1. k = Number of bits after the first zero in the encoded data Then Divisor = 2^k

2. Quotient = No. of ones before the first zero

3. Reminder = Binary (next k bits)

4. Input = Quotient × Divisor + Reminder

3. 3 LZMA Compression:

LZMA is the optimized version of LZ77 in which the compression rate keeping the memory requirements low. The process involved in LZMA compression and decompression comprises three major steps on both sides namely delta encoding/decoding, Sliding Dictionary Encoding/Decoding (LZ77) and Range encoding/decoding. The block diagram of LZMA is as shown in figure 4 and the steps are explained below.

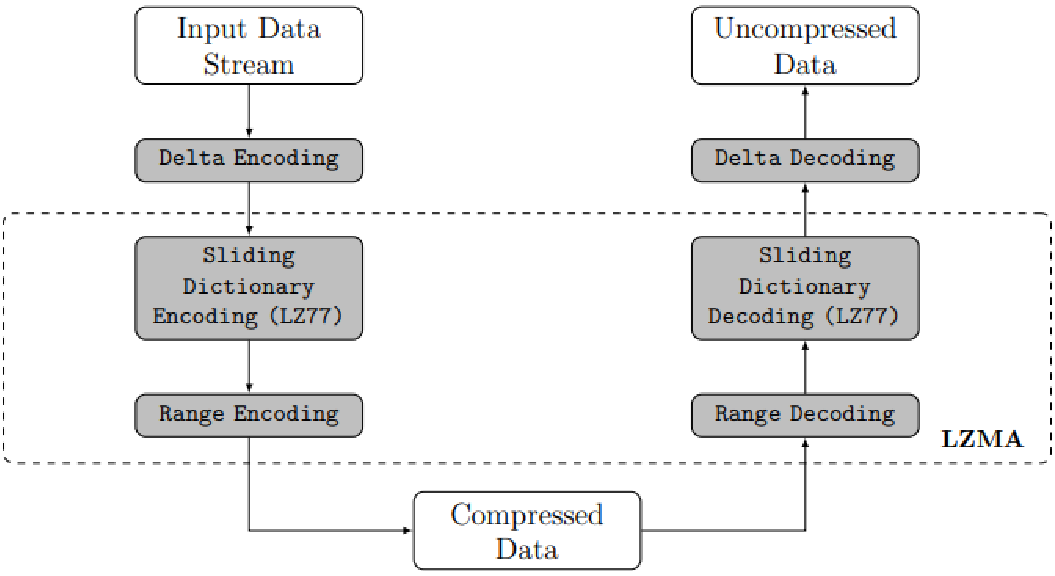

Fig 4: Block diagram of LZMA Compression

Step1 Delta encoding – In this step, the input stream is encoded in which the first byte is kept as it is and the subsequent ones are represented as the differences (delta) between the current and previous bytes.

Step2 Sliding dictionary encoding – This step represents LZ77 algorithm which performs faster searches using optimized search algorithms The output of this step is similar to that of LZ77 which is a triplet sequence – distance from the string in look-ahead buffer to its match string in the search buffer, string length, and next input.

Step 3 Range encoding – basing on few probabilistic algorithms the range in which the encoding must take place is estimated and the data received from step2 is encoded using this range.

It is well known that the decoding process will be the steps in reverse to the encoding mechanism.

3.4 Computation of Energy Efficiency:

The ultimate objective of our model is to increase the energy efficiency which means the energy consumption to be made less. The energy computation after applying data compression techniques is as follows:

Typically, the energy required to transmit a message M_i of 'b' bits for a distance d_t is:

for each distance d_t in P:

$$E_{tx} \leftarrow b * d_t * E_T$$

$$E_{rx} \leftarrow b * E_R$$

$$E_{M_i} \leftarrow E_{M_i} + E_{tx} + E_{rx}$$

In the above representation, E_{tx} and E_{rx} stands for Transmission and Reception energies respectively, while E_{M_i} is the total energy required to process a message. However, after applying data compression, the number of bits change at two levels i.e., from Node to cluster head and from cluster head to base station. Moreover, there are 'i' messages to be sent at once and also the data size alters which is to be transmitted through a distance d_t. N_{jk} represents node j transferring data to Cluster Head k (CH_k) and BS is the base station. IDestn denotes the intermediate destination.

The energy and average energy consumptions are computed as follows:

$E_{Y_k} \leftarrow 0$

$E_{Z_k} \leftarrow 0$

Source ← ip-addr(N_{jk})

IDestn ← ip-addr(CH_k)

Destn ← ip-addr(BS)

P ← build_path(Source, IDestn)

Q ← build_path(IDestn, Destn)

$X_k \leftarrow \| M_i$

$Y_k \leftarrow FELACS_{N_{jk}CH_k}(X_k)$

b_k ← num_bits(Y_k)

for each distance d_t in P:

$$E_{tx} \leftarrow b_k * d_t * E_T$$

$$E_{rx} \leftarrow b_k * E_R$$

$$E_{Y_k} \leftarrow E_{Y_k} + E_{tx} + E_{rx}$$

$Z_k \leftarrow LZMA_{CH_k BS}(Y_k)$

b_r ← num_bits(Z_k)

for each distance d_y in Q:

$E_{tx} \leftarrow b_r * d_y * E_T$

$E_{rx} \leftarrow b_r * E_R$

$$E_{Z_k} \leftarrow E_{Z_k} + E_{tx} + E_{rx}$$

Now the total energy required to transmit the messages in X_k is given as:

$$E_{X_k} = E_{Y_k} + E_{Z_k}$$

In case of 'n' number of data transmissions, the total energy required is:

$$E_{Total} = \sum_{k=1}^{n} E_{X_k}$$

The average energy consumption for transmitting 'i' messages in a data transfer is

$$E_{Avg_k} = \frac{1}{b_k + b_r} * E_{X_k}$$

The average energy consumption for performing 'n' such data transfers is

$$E_{Avg} = \frac{1}{n} * \sum_{k=1}^{n} E_{Avg_k}$$

E_{Y_k} & E_{Z_k} are the energy consumptions related to the respective data transfers from nodes to cluster head and cluster head to base station. Initially they are considered to be zero. Source and destination are identified. Then the transmission path is built between source and destination via the intermediate destinations if any. Once the path is built, FELACS compression is applied on the data which is to be transmitted between the source and intermediate destination. During the data transfer, the transmission and reception energies are computed. Similarly total energy requirement is computed for the further compressed data being transmitted to the destination. At this stage the compression is performed using LZMA algorithm. Finally, E_{X_k} is the total energy required to transmit the messages. E_{Avg_k} and E_{Avg} are the average energies for transmitting messages and for 'n' such transmissions. b_k & b_r are the number of bits in the messages on path P and Q respectively.

3.5. Results and Discussion:

Data compression leads to fast transmission, savings in energy consumption and also adds a flavour of security. The simulation is carried out using python 3.10 on Intel i5 machine. The performance of the above implementation is measured in terms of following parameters: Data size after compression, Compression ratio, Compression factor, Percentage of data saving, Root Mean Square Error, speed and energy efficiency.

Performance comparison for three different data sizes:

The experiment is repeated for three inputs of sizes, 256 bits, 512 bits and 4000 bits and the performance with respect to various parameters is depicted in table 1and figures 5 and 6.

Table 1: Comparison of Performance parameters with various data sizes

Parameter	Experimental results					
	uncompressed	Compressed	uncompressed	Compressed	uncompressed	Compressed
Data size (no. of bits)	256	108	512	136	4000	464
Compression Ratio	--	2.37	--	3.76	--	8.62
Compression Factor	--	0.421	--	0.265	--	0.116
Percentage of data savings	--	57.9	--	73.5	--	88.4
Speed (time consumption in seconds)	0.256	0.108	0.512	0.136	4	0.464
Average Energy Consumption (in Joules)	0.01664	0.00702	0.03328	0.00884	0.26	0.03016

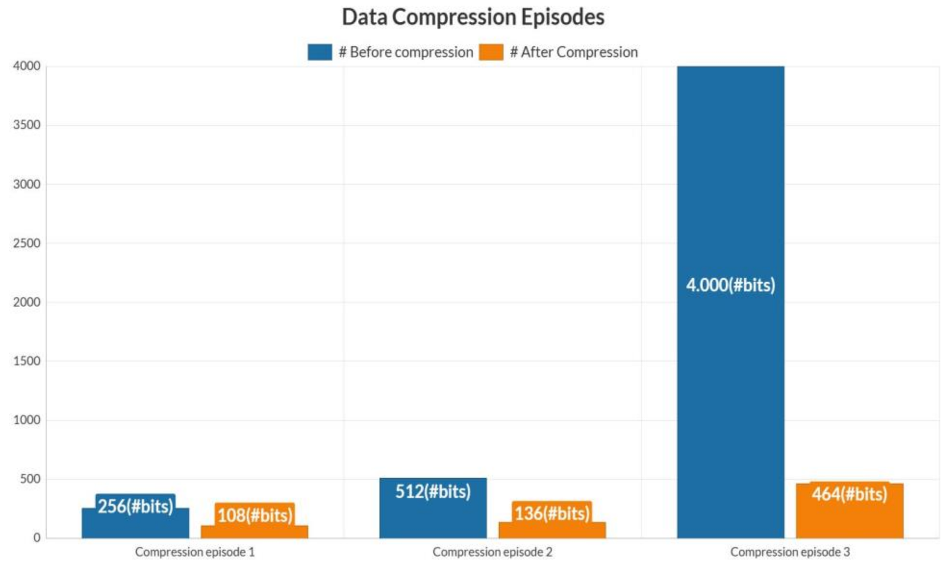

Fig 5: Compression for data sizes 256, 512 and 4000 bits

The above graph and tabulated values indicate that the compression is highly efficient and the data savings also confirm the efficacy. Also the compression technique offered optimal energy consumption which is depicted in figure . In both the graphs, the X - axis shows the episodes of compression and energy efficiency for three different data sizes. Y - axis represents the number of bits in case of data compression size and number of joules in case of energy efficiency.

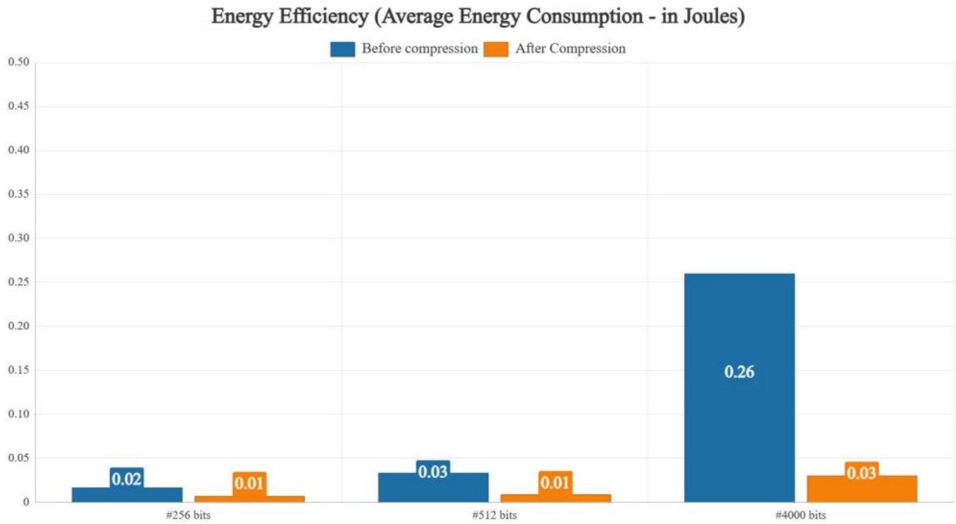

Fig 6: Average energy consumption for data sizes 256, 512 and 4000 bits

Performance comparison with the contributions of other researchers:

In this subsection the performance of proposed compression technique FELZMACS is compared with the performance of techniques proposed by other researchers. The proposed technique outperformed in compressing the data and also the energy savings. The comparison of various parameters is depicted in table 2 while the data size after compression is depicted in figure 7.

Table 2: Comparing the performance with that of contributions of various researchers

Parameter	Techniques			
	Adaptive Huffman Coding[22]	Existing RGC[22]	MARGC [22]	Proposed Technique (FELZMACS)
Data size (no. of bits)	2411	3027	2102	464

Compression Ratio	1.659	1.321	1.903	8.62
Compression Factor	0.603	0.757	0.526	0.116
Percentage of data savings	39.7	24.325	47.45	88.4

In addition to the savings in data size, transmission time, energy requirements, indirectly the security aspect is also infused into the network. In general, if there is a data on the medium which is known, then the attacker doesn't require any efforts to invest in and also it could be exploited very quickly. On the other hand, if the format of the data being transmitted is intentionally changed, then the attacker may have to put more efforts to decode the data.

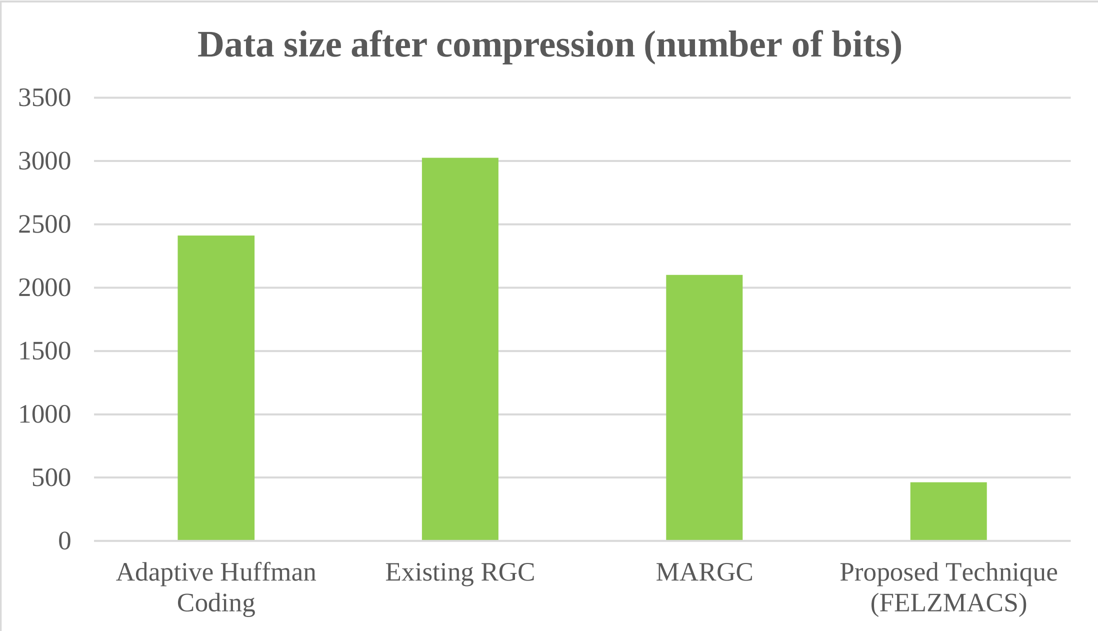

Fig 7: Comparing the compression performance with that of contributions of various researchers

As data compression in some or other way changes the format of data, certainly it could be affirmed security is also said to be provided to the data. With the above implementation, the proposed model FELZMACS is said to be efficient in performance.

4. Conclusion and Future scope

Wireless Sensor Networks applications are the apex technological advancements in the current scenario all over the world and in this aspect data transmission and energy requirements are the constraints that are limiting their superiority. To address these constraints researchers are continuously making several contributions. in this context it is to cite that efficient data compression techniques are highly recommendable which certainly reduces the data size and shoulder the responsibility for fast transmission and energy savings. To be a part of the solution, in this paper a novel data compression technique "Fast and Efficient Lempel Ziv Markov Chain Adaptive Compression Scheme" (FELZMACS) which is a hybrid approach composed of two predominant techniques "Fast and Efficient Adaptive Compression Scheme (FELACS)" and "Lempel Ziv Markov Chain Algorithm (LZMA)". The proposed technique exhibited authoritative performance. The data savings percentage is far better when compared with various schemes. As future work it is to mention that such hybrid algorithms could be introduced which deal with image, audio, video data and offer promising performance.

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