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ENERGY AND DELAY AWARE DATALINK LAYER PROTOCOLS FOR WIRELESS BODY AREA NETWORK

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ABSTRACT

A wireless Body Area Network (WBAN) is a collection of smart bio sensors that are deployed wirelessly in, on or near the human body to perform data collection and data transmission. Each node in the network is embedded with limited battery, but it is almost very difficult to change or recharge batteries. Major sources of energy waste are idle listening, control packet overhead, over emitting, over hearing and collision. MAC protocols plays an essential role to control the operation of radio transceiver and significantly affect the energy consumption of the whole network. This paper investigates the energy efficient and delay aware MAC protocols for WBAN. The foremost benefits of MAC protocols along with their limitations are elaborated. Finally, the open research problems with respect to different techniques and feasible solutions for energy minimization, traffic control mechanisms for collision, and delay are summarized.

Keywords—*Wireless Body Area Network; MAC protocols; Energy Consumption; Delay; Priority based Data Transmission*

1. INTRODUCTION

A typical Wireless Body Area Network consists of a collection of bio sensor devices and a network coordinator that collects information from the patient body and sends it to the base station for monitoring and evaluation by the healthcare professionals. Also, the health status of the patient is updated wirelessly to cloud server [1]. If an emergency data is detected, an alert will be created via the internet to inform the patient and the medical staff members [2]. The recent technologies such as Cloud, Fog computing, IoT, Big data are used in different aspects of healthcare monitoring applications. The key benefits of these technologies provide low cost software services, low latency, efficient bandwidth utilization and capability of massive data storage [3]. Fig.1 The overall architecture diagram of WBAN system.

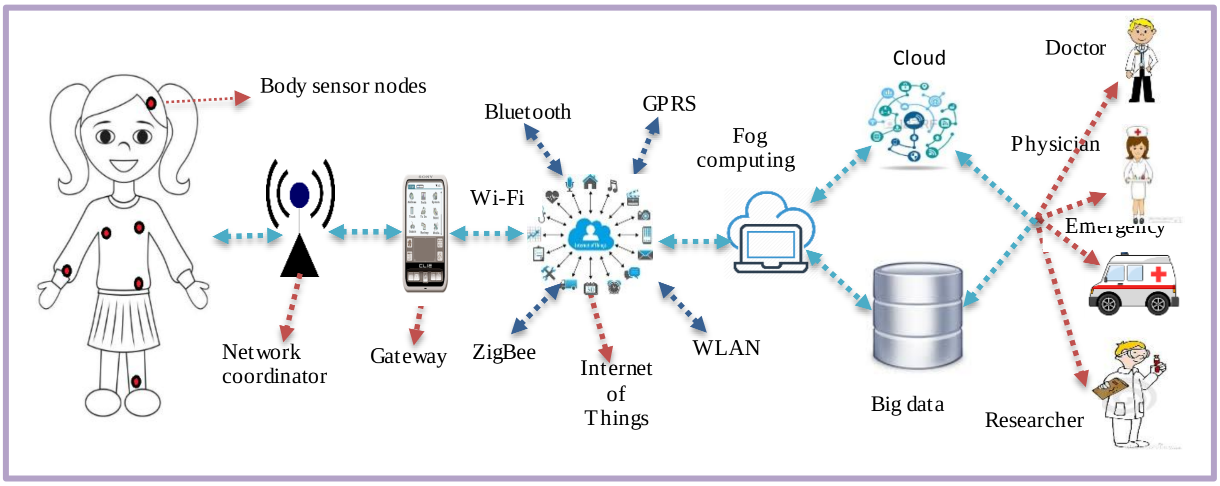

Fig.1 The overall architecture of WBAN

Body Sensor nodes can be a wearable or an implanted device, so it is very difficult to replace or recharge very often. The MAC layer protocol determines the way sensor nodes use wireless medium and allocates limited channel resources for sensor nodes [4], so research on energy efficient MAC protocols is a significant issue for improving the performance of WBAN. The new IEEE 802.15.6 standard includes [5] different types of medium access, namely CSMA/CA, scheduled, and polling access schemes, or hybrid techniques. The following Fig. 2 demonstrates the various issues related to energy consumption in data communication. The major sources of energy consumption are control overhead, idle listening, over emitting, over hearing and packet collisions [6]. Priority is another crucial problem to effectively avoid the delay, conflicts and collision caused when the huge number of sensor nodes are participated and need to transmit data, this causes more energy wastage and delay [7]. Since, analysing different priority based MAC techniques are necessary for transmitting the lifetime critical data. The rest of this paper is designed as follows: Section II provides the various challenges of existing MAC protocols in WBAN. Section III discusses about the open research problems with possible solutions. Finally, the paper is concluded in Section IV.

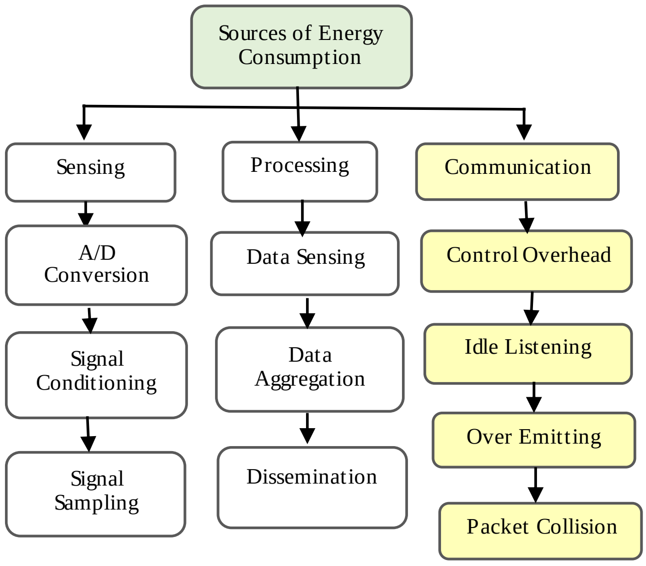

Fig.2. Sources of Energy Consumption in WBAN

2. CHALLENGES OF ENERGY-DELAY AWARE MAC PROTOCOLS

This section reviews the recent challenges of MAC protocols in WBAN including Energy consumption, Delay and Priority. Generally, two major MAC schemes are used for WBAN. They are Random Access MAC protocols (CSMA / CA) and Schedule based MAC protocols (TDMA). In random access MAC protocols [8], the sensor nodes compete for channel access prior to data transmission. The advantages of CSMA/CA are adaptability to frequent network changes, also there is no time constraint for synchronization and scalability. In Schedule based MAC protocols, such as TDMA protocol, the channel is divided into time slots. It may be fixed or variable time slot duration. Each sensor node is assigned time slot duration by a coordinator. The sensor node transmits within that time slot duration. However, this type of MAC protocols eliminates the packet collision, idle listening and overhearing [9].

In order to reduce the energy consumption [10], various energy efficient MAC protocols have been proposed. The following Table 1 presents the performance metrics of both the Random Access and the Scheduled MAC Protocols. Body MAC (B-MAC) protocol is mainly based on TDMA technique. With the help of this protocol, the idle listening and control packet overhead have been reduced by allocating three bandwidth management methods: Burst Bandwidth, Periodic Bandwidth and Adjust Bandwidth in order to improve energy efficiency.

Performance Metrics	**Random Access MAC Protocol**	**Scheduled MAC Protocol**
	Carrier Sense Multiple Access Protocol (CSMA)	Time Division Multiple Access Protocol (TDMA)
Energy Consumption	High	Low
Packet Delay	Variable	Constant
Network Traffic	Low	High
Data Transmission	Low	High

Table. 1 Comparison Between CSMA and TDMA Protocols

Since nodes and coordinator are synchronized in proper time, nodes can enter into sleep mode and wake up only when they have data to transmit to the coordinator. The slot allocation in CFP is collision free, which improves packet transmission and hence saves energy [11]. Directional MAC (D-MAC) protocol [12] has introduced traffic adaptive duty cycle concept to extend the sleep duration of each nodes by regulating duty cycle adaptively. Thus, DMAC achieves low energy in the coordinator node and higher energy efficiency in the body sensor nodes. Dynamic TDMA (DTDMA) protocol has designed for reservation based time slotted ALOHA in CAP field of super frame to reduce collisions and to enhance power efficiency. In this, the adaptive allocation of the time slots in a super frame, network coordinator changes the duty cycle adaptively based on the incoming traffic loads [13].

Time out MAC (T-MAC) protocol utilized [14] flexible duty cycles for improving energy efficiency. In T-MAC, the node wakes up after time slot assignment, send awaiting messages. If there is no activation event, the node goes back to sleep mode again. Whenever, a node sends RTS and if does not receive any CTS messages, then again sends RTS messages more than two times before going to sleep mode. Also, it uses future RTS messages to transmit the priority data by eliminating untimely sleep problem. This method minimizes the delay and outperforms other MAC protocols under flexible loads. In [15], a TDMA based Heart beat driven MAC (H-MAC) protocol has implemented using star topology. H-MAC assigns dedicated time slots to sensor nodes for communication. Also, H-MAC maintains synchronization required for TDMA approach without using periodic control messages. This mechanism used to minimize overall energy consumption.

Traffic aware MAC (Ta-MAC) utilizes [16] traffic information to enable low-power communication. Two wakeup mechanisms has considered based on the traffic load and wake up radio. First method controls normal traffic by moderating the traffic patterns of body sensor nodes, emergency and on-demand traffic are maintained using a wakeup radio mechanism. In this protocol, the traffic pattern is defined by the coordinator node, in a static topology. Therefore, it could not work efficient in dynamic topology and dynamic traffic patterns. Traffic Aware Dynamic (TAD-MAC) protocol [17] has developed using traffic status register bank for dynamic variation of wake up interval. Where, each node holds a register bank with traffic status based on the data received from the neighbor nodes. This technique used the wake-up interval to moderate the state of fixed and variable traffic rates, thus results better energy efficiency. The energy consumption due to idle listening and unnecessary wake-up beacon transmission are reduced. ZigBee MAC (Z-MAC) protocol has considered two different methods including CSMA/CA and TDMA. In which, CSMA/CA technique produced average results but TDMA scheme achieved better result in energy conservation [18].

Priority Based Adaptive Timeslot Allocation (PTA MAC) has presented [19] to prioritize the data using adaptive time slot allocation scheme. The CAP field is divided C1 and C2 type of data and remaining phase can be used in transmitting all kind of data. The emergency data are forwarded during CAP period through CSMA/CA approach. This protocol is also able to manage with dynamic network. Context-aware MAC (CA-MAC) protocol which also uses hybrid super frame structure. In CA-MAC, the traffic aware adjustment of transmission priority and channel-aware adjustment of access mechanism leads to desired efficiency and reliability. CA-MAC dynamically changes the sampling rate and scheduled time slots for each sensor nodes [20].

Adaptive Medium Access Control (A-MAC) protocol [21] has established with linear programming models for the minimization of energy consumption and maximization of dataflow rate. In this, adaptive guard band assignment technique and sleep/wakeup techniques are used to overcome collision and overhearing problems. Baseline MAC (B-MAC) has considered advanced CSMA/CA approach [22]. This protocol provides better results in throughput but fails to improve the energy efficiency. Sensor MAC (S-MAC) protocol has proposed [23] using a periodic listen and sleep mechanism to establish a low duty cycle operation on each node. Each node's radio turns into sleep state and then wakes up, listens to communicate with any other node. This protocol is similar to TMAC, but the only difference is that it has fixed duty cycle. This protocol achieves better energy efficiency. Priority-guaranteed MAC (P-MAC) protocol has developed [24] a super frame with fixed time slot interval. At the initial stage of each frame, nodes turn on their radio and go to sleep state if there are no packets arrive in a particular period and also listen the channel for long duration. However, complex super frame structure and inadaptability to emergency traffic are major

drawbacks of this protocol. Lightweight MAC (L-MAC) protocol that takes into relation the physical layer properties [25]. Time slots have traffic control section and a fixed length data section. It is a simple schedule based MAC protocol which uses round robin technique is followed by the nodes to send data. The main aim of the protocol is to decrease the number of transceiver switches, to limit the complexity of implementation and to make the sensor nodes sleep interval adaptive to the amount of data traffics. LMAC protocol increases the network lifetime. Battery aware MAC (Ba-MAC) protocol has developed [26] to maximize the lifetime of the network a cross layer designed MAC protocol have been proposed with cross layer design. Various parameters have been taken into account to access the medium electrochemical properties, packet queuing, time varying wireless fading channel.

Medical Medium Access Control (MedMAC) protocol has improved the channel access mechanism and reduce energy dissipation. MedMAC uses TDMA approach for time slots assignment to body nodes for data communication. However, these assigned time slots are flexible and diverge based on nodes requirements. The protocol focuses only on low data rate medical applications [27]. Energy Adaptive MAC (EA-MAC) has proposed [28] to adjust the duty cycle dynamically with respect of the amount of reaped energy and the contention period of nodes.

All Dynamic MAC (AD-MAC) protocol has adopted [29] dynamic priority control, adaptive timeslot allocation and variable length allocation of different access periods to achieve reliable transmission in the situation of low delay and low power consumption. The super frame structure can greatly reduce the control difficulty and compared to IEEE 802.15.6, also it reduces the length of beacon field. This method has verified with the existing techniques of both AD-MAC and CA-MAC. The Wise MAC (Wise-MAC) protocol has designed [30] using LPL mechanism. In which, the CSMA and a preamble sampling method used to minimize idle listening problem. A Priority-based Adaptive MAC (PA-MAC) protocol has proposed for utilizing the unused bandwidth. In this method, time slots are allocated in dynamic way based on the traffic priority. Further, multiple channels are employed to reduce access delays in an efficient way. Also, this protocol used both CAP and CFP to transfer continuous and more number of data packets to the coordinator node. Emergency Response MAC (ER-MAC) protocol [32] has implemented to avoid extra energy wastage. The idle listening problem has eliminated using the concept of periodic listen and sleep mechanism. But it may cause the overhearing problem. Quasi Sleep Pre-empt Supported MAC (QS-PS MAC) has proposed using TDMA scheme, where the nodes transmit packets to coordinator node in fixed slots and enters into Q-sleep mode in other slots. For normal traffics, QS-PS runs based on TDMA and for emergency packets it will broadcast awakening message to all nodes in Q-sleep mode.

Publication Year	Literature	Protocols used
2010	[11]	BodyMAC
2010	[12]	D-MAC
2010	[13]	DTDMA-MAC
2012	[14]	T-MAC
2012	[15]	H-MAC
2012	[16]	Ta-MAC
2012	[17]	TAD-MAC
2013	[18]	Z-MAC
2013	[19]	PTA-MAC
2013	[20]	CA-MAC
2014	[21]	A-MAC
2014	[22]	Baseline MAC
2014	[23]	S-MAC
2015	[24]	P-MAC
2015	[25]	L-MAC
2015	[26]	Ba-MAC
2015	[27]	Med-MAC
2015	[28]	EA-MAC
2015	[29]	AD-MAC
2016	[30]	Wise MAC
2016	[31]	PA-MAC
2016	[32]	ER-MAC
2016	[33]	QS-PS-MAC
2016	[34]	EEAWD-MAC

2016	[35]	TTR-MAC
2016	[36]	DTD-MAC
2016	[37]	EBM-MAC

Table.2 Summary of Different MAC Protocols Used in WBAN

In Quasi-sleep mode, node enters into sleep when dedicated time slot elapses and then wakes up for next assigned time slot. Hence, it has achieved high energy efficiency and low delay for both normal and emergency data packet transmission [33]. Enhanced Energy Aware Wake up on Demand (EEAWD-MAC) MAC protocol [34] has introduced to minimize the power consumption.

Protocols used	MAC Techniques	Benefits	Drawbacks
BodyMAC [11]	CSMA/Scheduling	Simplicity, good packet delivery rate, high throughput, low overhead	Overhearing problem is not solved, long preamble increases the power Consumption and good only for normal traffic applications
D-MAC [12]	CSMA/Scheduling	Less delay and energy consumption	Collision avoidance are not utilized, leading to collisions
DTDMA-MAC [13]	CSMA/Scheduling	Good energy efficiency, network stability, bandwidth utilization and reduce packet collision	It does not support emergency and on-demand traffics
T-MAC [14]	CSMA/Scheduling	Packets are sent in burst, better delay, gives better result under variable load	Suffers from sleeping problems
H-MAC [15]	TDMA Scheduling/Listening	Bandwidth efficiency is improved	Single point problem exists
Ta-MAC [16]	TDMA Scheduling	Low delay and energy consumption	It does not work efficient in dynamic topology
TAD-MAC [17]	TDMA Scheduling	Ultra-low energy consumption from idle listening, overhearing, collisions	Unnecessary wake up beacon transmission

ZigBee MAC [18]	CSMA/Scheduling	Support high data rate and average throughput	More energy consumption
PTA-MAC [19]	CSMA listening	Improved QoS with dynamic network size	No guaranteed transmission of critical data packets
CA-MAC [20]	TDMA Scheduling	Collision is omitted and delay, energy is improved	Emergency data is not considered
A-MAC [21]	TDMA scheduling	Increased data flow and minimized the energy consumption	It does not allow nodes to access channel after every fresh data that leads high delay on critical data
Baseline MAC [22]	CSMA listening	Improved latency and throughput	Support only normal and on-demand traffic
S-MAC [23]	CSMA/Scheduling	Less delay, time synchronization overhead is prevented due to sleep schedules	Low throughput, overhearing and collision may cause if the packet is not destined to listening node, better only for normal traffic applications
P-MAC [24]	CSMA/Listening	High throughput	Adaptation to changes the duty cycles might be slow and support only for delay sensitive data applications
L-MAC [25]	CSMA/Scheduling	Enhanced the network life time and decrease the unnecessary transmissions	Overhearing problem may occur
Ba-MAC [26]	TDMA scheduling	Reliability and timely delivery of packets is achieved	High average delay and packet drop rate
MedMAC [27]	TDMA listening	Energy consumption due to collision is avoided	Low data rate
EA-MAC [28]	TDMA Scheduling	Improved energy	It does not support

		efficiency using dynamic adjustment of the duty cycles	critical data traffic
AD-MAC [29]	TDMA Scheduling	Low latency and low power consumption	No of beacon signal increases the delay during the data transmission
Wise MAC [30]	Np-CSMA/Listening	Adaptive to different traffic loads	Distributed sleep-listen scheduling limits throughput
PA-MAC [31]	TDMA/Listening	Less delay	Collision problem due to heterogeneous traffic loads
ER-MAC [32]	CSMA/Scheduling	No contention mechanism is involved	Overhearing occurs while selecting critical nodes
QS-PS-MAC [33]	TDMA Scheduling	High energy efficiency and low delay	Take more time to reallocation of time slots
EEAWD-MAC [34]	CSMA/Scheduling	Improve latency and real time data transmission	Correlation of multi-priority data is not considered
TTR-MAC [35]	TDMA Scheduling	Highly decreases the average delay	Priority based reservation technique is not considered
DTD-MAC [36]	TDMA Scheduling/listening	Less energy consumption	Transmission delay and packet loss may occur due to urgent data transmission
EBM-MAC [37]	CSMA/Scheduling	Improved the reliability, energy efficiency, throughput and delay	No priority based mechanism his considered to transfer critical data

Table.3 Comparison of Different Energy-Delay Aware MAC Protocols

This technique established a mathematical framework using integer liner programming. But it has two mathematical issues such as the set covering and multi-commodity flow problems. Token based Two Round Reservation MAC (TTR-MAC) protocol [35] has implemented based on

IEEE 802.15.6 standard with consideration of health monitoring applications. In this, one round reservation is modelled for periodic data and two round reservations is generated adaptively for burst data to save energy. Furthermore, TTR MAC protocol assigns suitable number of allocation slots to nodes in different data arrival rates. A token is presented on the basis of user priority and emergency index to indicate the transmission order of nodes with burst data, which extremely decreases the average delay.

The Decrease of Transmission Delay MAC (DTD-MAC) protocol has presented for handling both normal and urgent data with the same maximum delay. If a node has reached the maximum transmission delay of 250ms, then GTS has been allocated before other nodes regardless of the normal data decided by the network coordinator [36]. Energy Balanced Mechanism (EBM) contains one extra feature of tree-based hierarchy along with all similar specifications of Body MAC protocol to improve energy efficiency, throughput and delay [37]. This EBM protocol has produced better results with existing MAC protocols.

3. OPEN RESEARCH PROBLEMS AND FUTURE SCOPE

The most energy consuming and energy constraint unit in a sensor node is wireless radio. The radio of a node can be in four states: Transmit, Receive, Idle and Sleep. Each state is having different degree of energy consumption. The MAC layer provides most control of the transceiver of a node so that all nodes will efficiently share common medium by switching the radio on and off. Still, there are so many issues need to be addressed in the area of WBAN. Since, there is a very strong need to develop reliable, congestion free, low overhead, low power and priority based MAC protocols. So, to increase network lifetime by reducing energy consumption by removing one or more above mentioned problem.

Queuing techniques are also considered to provide guaranteed QoS to different classes of traffic load. Authors propose the Markov chain process [38] to consider all transition probabilities from one state to another. In which, a new arrival of packet can identify the corresponding type of packet is in service only, then the packet with already arrived packet in the previous state have been served. Also, they used three different types of queue to handle various traffic load, with addition of one empty queue for idle cases distinctly from non-empty queues. However, the size of the queue length is very important to schedule the packets in WBAN. With multiple queues, the chance of packet loss and utilization of bandwidth decreases as compared with a single queue model. Thus, the average delay will be increased because packets enqueued behind a large number of other packets. Since, reducing the queue length is a challenging factor for efficient bandwidth usage and minimization of average delay. In [39], the data with first priority reaches the maximum delay time (250ms) that packet has been transmitted with assigned time slot to reduce the additional delay and packet loss. With no assigned time slot, if no other packets reached the maximum delay, then the data in buffer node can be transmitted based on the priority of existing nodes.

To avoid data loss in WBAN during transmission, the fault tolerance technique will be more useful to provide reliability assurance for the nodes. In this, the data from the different body nodes are analyzed by the coordinator to classify the fault related data, then dynamically changes fault-tolerant priority of the body nodes, thus guarantee the priorities of critical sensors. However, TDMA based MAC protocols are more power efficient than other MAC protocols but the packet generated by node may suffer three type of delays as it reaches sink such as transmission delay, queuing delay and propagation delay. Tree based mechanism has been implemented using TDMA technique in [33]. In which, nodes transmit their packets in the assigned time slots, while entering the Q-Sleep mode in other slots in order to save energy. whenever nodes detect emergency packet, then it can broadcast a special message to wake up the whole network. At every time, the nodes need to turn on their radio that may cause high energy consumption.

To avoid delay and energy consumption of nodes, authors use [41] CSMA/CA mechanism for normal traffic and only the priority data is transmitted through TDMA based time slots. To handle emergency data, the network coordinator node transmits additional beacon messages that leads to more energy consumption. Therefore, the reduction of extra listening period during the emergency data transmission is still a main challenge because it is difficult to predict which node will transmit critical data in the next cycle.

In Token-based Two-Round Reservation MAC (TTR MAC) protocol [35], one-round reservation is used to handle periodic data and two-round reservation is considered for burst data to increase the energy efficiency. In which, the number of time slots has allocated to every node in different data arrival rates. A severity index has been included to specify the transmission order of nodes. In first round reservation, the request frame piggybacks the corresponding data for reservation. In order to allocate the time slots, nodes add its periodic data arrival rate and duty cycle information into the request frame and then transmit it to the network coordinator. Then, the node waits the Immediate Acknowledgement (I-ACK). If any two frames are received by node within the fixed time interval, again it will retransmit the request frame. The retransmission of whole packets after some bits might be lost, and also this process consumes more energy. By making use of some error detection techniques, the packet loss will be eradicated. Also, this approach makes use of special control message which the receiving node of packet sends back to the sender. In this, the sender keeps on storing the packet until it receives the acknowledgement. This mechanism results in extra overhead on network in term of bandwidth and more energy consumption due to extra control messages.

4. CONCLUSION

The prime cogitation of WBAN is to maximize the network's lifetime. Various existing data link layer protocols have been analysed with the main focus on energy consumption, priority and delay. Moreover, the body sensor nodes should be provident in energy consumption. However, the contention and scheduling based MAC protocols are unable to accommodate critical, emergency, normal and on demand traffic loads in efficient way. Each protocol has some benefits and limitations mentioned above. Since, the design of MAC protocols with high reliability, less overhead, minimum delay and energy efficiency for WBAN are the most vital research problems. In future, the WBAN specific cross layer approach is necessary to eliminate these potential drawbacks and improve the performance in some extent over the traditional layered approach.

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