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A Review of Physical, Data and Network Layer Specification and its Protocols for Wireless Sensor Network

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Abstract: Wireless sensor network is a group of smart sensors, each capable of sensing, processing and communicating the data or messages when any event occurs. When nodes deployed in numbers it form a network which collectively monitor the state of the phenomenon activity of physical world. Its applications and potential benefits are remarkable and seem only limited by imagination. The interdisciplinary property makes the challenges wide and deep for design network protocols, efficient power utilization, programming models and application areas. This survey paper focuses on the basic of WSN technology and its design factors. It also focuses on the physical layer issues, data link layer protocols and its services and protocols used in layers.
Key words: sensor node, Design factor, protocol stack, and layers, MAC, routing protocol.

I. Introduction of wireless sensor network

A wireless sensor network (WSN) is a wireless communication network that consists of sensor units (nodes), which monitor specific physical or environmental events or phenomena, such as temperature changes, sound (noise), pressure, vibration or motion of object, at different location. WSN was first motivated and developed by military purposes in order to do battlefield surveillance. Now a day, new technologies have reduced the size of nodes, hardware cost, making cost and power of these sensor nodes. The development of wireless interfaces in various areas makes the WSN one of the most useful networks for wireless communication [1].
Wireless sensor network consist of various components which is used to make WSN like sensor nodes, an interconnecting wireless network, Base Station (Sink Node), a set of computing devices at the base station (or beyond) to gathered, analyze and interpret the received data from the various nodes. Sometimes the computing is done through the network itself [1].

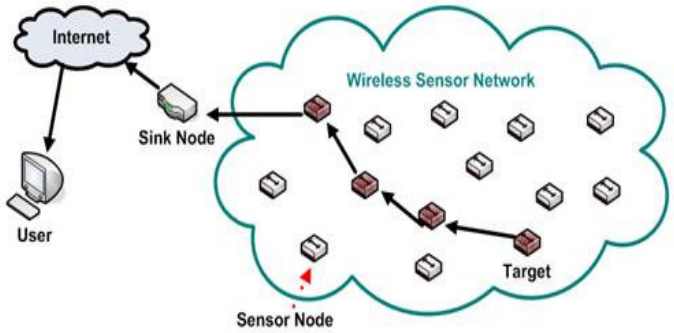

Figure.1

Sensor nodes are low-cost and low-power devices used to collect the desired data and store and forward it to the base (sink) station. A sensor node consist of three main units (shown inFig.2), the sensor nodes are equipped

with a sensing unit, processing unit and power unit. Each unit also used other components like processor, storage, mobilize and ADC components [1]

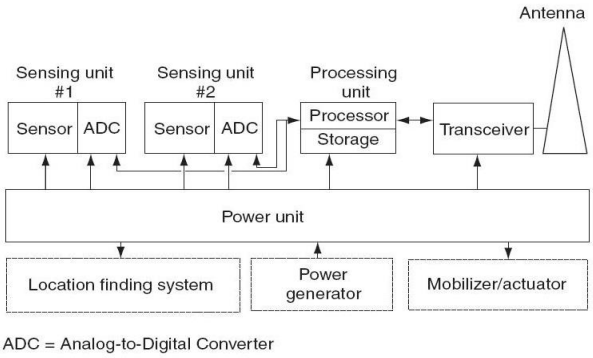

Figure.2

Functionality of sensor nodes depends on the working ability of the node, either being the source of the data which senses the event then transmits it, or just received data from other sources then forwards it to other sensor nodes in order to reach the base (sink) station. Actually, this functionality depends on the sensor network architecture used and design for specific application.

The size of a single sensor node can vary from each other depends upon the hardware and application where it is used. The cost of sensor nodes is also variable, ranging from hundreds of rupees to thousand of rupees, depending on the size, uses and the complexity of every sensor nodes [1].

II. Design factors of wireless sensor network

The designing of WSN's protocol involves various challenges. Design factors focus on energy utilization and maximization of nodes. Power consumption must be reduced as possible to increase the life time of the network. Various factors are also taken consideration like hardware and software constraints of sensors, modulation techniques, Location finding system, antenna, and power amplifier [2].

Major Design factors involve in WSN are as follows:

a. Limited energy capacity
b. Sensor locations
c. Limited hardware resources
d. Massive and random node deployment
e. Network characteristics and unreliable environment
f. Data Aggregation
g. Transmission media
h. Scalability

All factors used and varies according to type of network, application and node properties of WSN. Power consumption must be reduced as possible to increase the life time of the network. Various factors are also taken consideration like hardware and software constraints of sensors, location finding system, modulation techniques, antenna, and power amplifier [2].

Physical layer specifications and protocols

Physical layer mainly focus on three phase system first is establishment of connection between node second is data transfer and management and last is termination of physical connections between two communicating nodes. It also transmits and receives a stream of bits /bytes and no data recognition at the physical layer. It also define the electrical specification like current, volts, power etc. mechanical properties like physical dimensions (size) and weight etc. and protocols for data transmission. In the physical layer various issues such as Modulation type, Signal processing, Frequency bands, sensing and communication range and the proposed protocols are also focused.

Communication channel

A sensor node uses all available frequency bands. ISM (Industrial radio, Scientific and Medical radio) radio bands which gives free radio frequency, huge broad spectrum allocation and global presence. The choices of unguided media (wireless transmission media) are Radio waves Frequency, Optical Communication (through Laser) and Infrared communication. Laser requires very less energy as compare to others but needs light of sight for communication. Unguided medium like Infrared needs no antenna for transceiver purpose but it is limited in the communication distance and due to this limitation not used in broadcasting purpose. Radio Frequency (RF) based communication is the most appropriate to most of the WSN applications. WSN's uses communication frequency band between 433 MHz to 2.4 GHz. The transceiver is used in sensor which worked as transmitter as well as receiver. The operational stages are Transmitting, Receiving, Idle and Sleep stage [3].

WSN use the radio frequency communication, it also use the standard protocols and technologies such as Wi-Fi, IEEE 802.15.1(Bluetooth), IEEE 802.15.4(Zigbee), 3G and WLAN. The available protocols support the WSN and these also provide the fundamental aspects of Modulation. A basic modulation technique used in wireless sensor communication is phase shift keying (PSK). Various schemes of PSK like Multiple PSK (M-PSK) or Binary PSK (BPSK) is also support the wireless communication. In PSK modulation the amplitude and frequency of the carrying signal are kept constant. Where logic 1 is represented by π-phase shift key and logic 0 is represented by 0-phase shift key [4].

Energy utilization and maximization is very important and consumption minimization is an also important when designing the Wireless Sensor Networks for physical layer. In addition to other effects such as diffraction, scattering, reflection, shadowing, multipath, and fading, energy efficient design of WSN is also important factor. In Figure3 it shows the power consumption of power by different components and stages of the sensor node [5, 6].

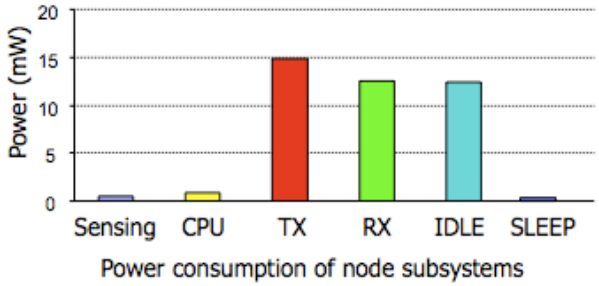

Figure.3

III. Available IEEE WSN Protocols

WSN uses the free ISM (Industrial radio, Scientific and Medical radio) bands. These bands can affect the performance of the channel due to the interference that may occur. For example, microwave ovens uses the frequency of 2.45MHz may overwhelm many WSN in the 2.4MHz band. IEEE protocols are broadly used and are mostly implemented in WSN technology. The most widely used WSN protocols are (a) IEEE 802.11 a/b/g/n (WLAN) (b) IEEE802.15.4 (ZigBee) (c) IEEE 802.15.1(Bluetooth) (d) wireless HART (e) ISA100. The data rates are differs from one protocol to another protocol. [5]

(a) IEEE 802.15.1 (Bluetooth)

Bluetooth is a wireless protocol for short-range communication which uses RF bands. it is designed for small variety of tasks which is less complex in nature, such as synchronization and file transfer. Bluetooth protocols available in two versions. First is Bluetooth1.2 with a maximum data rate of 1Mbps. Bluetooth2.0 is the new version of IEEE 802.1.5.1 Bluetooth and its maximum data rate is 3Mbps.

(b) IEEE 802.11 (WLAN)

Wireless LAN protocols are used for network which is large in size and involve high data rate. it also having various versions, different versions are used with its own applications.

1) High-bandwidth context voice over internet protocol (VoIP) uses IEEE 802.11g.
2) For Supporting quality of services (QoS) over wireless it uses IEEE 802.11e.
3) For Secure and reliable communications it uses IEEE 802.11i.

Different schemes of modulation are used in the IEEE 802.11(WLAN) family, some use Orthogonal Frequency-Division Multiplexing (OFDM) method and other uses Direct Sequence Spread Spectrum (DSSS) method.

(c) IEEE 802.15.4 (ZigBee)

Zigbee /802.15.4 is a technology developed as a global standard to comply with the needs of low cost and low power wireless networks. ZigBee is the preferred protocol to be deployed in WSN since it meets the requirements of low-cost and low-power WSNs for remote controlling and monitoring. Previous protocols provide high data rate in the expense of high power consumption, application complexity and higher cost.
Table 1 shows the comparison of different features and characteristics of WSN protocol with each other. [7]

	IEEE Protocols		
Property	**802.11 (WLAN)**	**802.15.1 (Bluetooth)**	**802.15.4 (ZigBee)**
Range (m)	**Up to 100**	**Up to 100**	**Up to 10**
Data throughput (Mbps)	**2 – 54**	**1 - 3**	**Up to 0.25**
Battery life	**Minutes to hours**	**Hours to days**	**Days to years**
Size Relationship	**Large**	**Smaller**	**Smallest**
Cost/Complexity	**> 6**	**1**	**0.2**

Table 1

IV. Data link layer protocol and Specification

Layer 2 of WSN i.e. Data link layer (DLL) is responsible for the reliable transmission of frames (also called packet). Data link layer is divided into two sub layer, the first is Medium Access Control (MAC) Sub layer and another is Logic Link Control (LLC). MAC Layer supports the congestion control and collisions avoidance. LLC layer support the several MAC layer options depending on the wireless network topology and its architecture. [8]

(A) Contention-Based Protocols for WSN

MAC Protocol for wireless sensor networks consumes less power, collisions detection and avoidance. It can be implemented with a small code size and memory requirements and efficient for a single application. It is tolerant to changing radio frequency and networking conditions.
The contention-based protocols are used especially in WSN because of its ability to minimize the energy waste. This is because of the option of Power Save (PS) mode to turn off their radios battery to conserve energy. This feature is mainly used for comparison between different protocols. There are various protocols available which support contention in WSN. Some of them are describe below [9]

(B) Sensor-MAC (SMAC) Protocol

SMAC protocol basically focuses on the effective utilization of energy of sensor node and network. Energy efficiency is the most important feature because most of the times a sensor node will be in idle listening; SMAC turns off the node transceiver from time to time (Figure4) Therefore, a node with a long data message will not give up the medium to other nodes until its whole message is transmitted. Due to this long data message shorter messages wait longer in the queue to get access to the WSN.

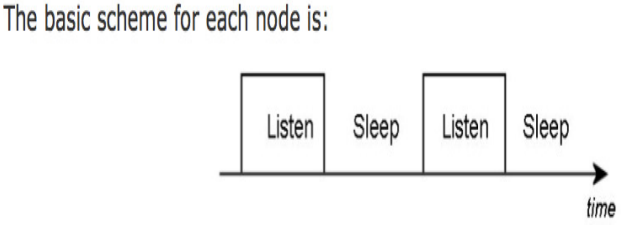

Figure.4

SMAC has the following features:

(1) Periodic Listen and Sleep.

Each node in the network turns OFF (for sleep) and ON (Listen) its transceiver periodically in the medium, as shown in Figure 4. The parameter to measure the percentage between wake-up periods to sleep period is called duty cycle and is given by
Duty Cycle= listen time/sleep cycle time = ON/OFF Cycle.

(2) Synchronization.

SMAC introduces a new packet (SYNC) to perform the synchronization task. At the initial deployment time period, every node keep listen to the channel or medium until one node broadcasts a SYNC Packet containing its communication schedule for data transferring. When Neighboring nodes receive this packet they will set their schedule according to the new schedule and broadcasts a SYNC packet to their neighbors too. Listen (ON) interval is divided into two parts: one for receiving SYNC packets and the other for receiving RTS (Request to send) packets. Figure 5 shows the basic operation process.

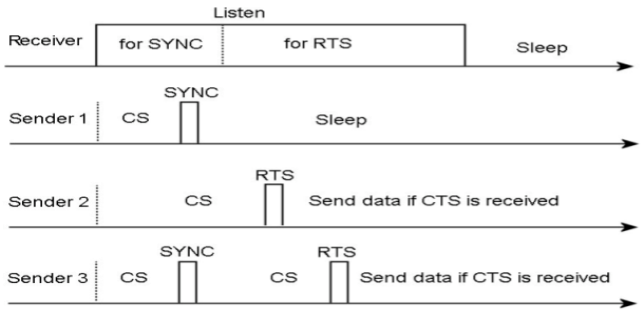

Figure.5

(3) Collision Avoidance.

SMAC uses a concept similar to the IEEE 802.11 WLAN for medium contention, where all immediate nodes of both the Receiver and transmitter will go to sleep upon receiving CTS (Clear to Send) packets and RTS (Ready to send) packet respectively. Some properties of SMAC are as follows

- Fixed duty cycle of active state and sleep state
- In SMAC protocol Throughput is reduced because only active part is used for communication.

- Latency rate increases because a message-generating event may occur during sleep state.

(C) Timeout-MAC (TMAC) Protocol

TMAC protocols maximize packet throughput, minimize latency, and provide fairness of network. TMAC protocol tries to enhance the energy utilization in SMAC by reducing the idle time. Most energy in traditional MAC protocols is wasted by idle listening and this is known as idle listening problem. In figure 6(a) it shows SMAC duty cycle; the arrow indicate transmit and receive messages.
A node in the listen stage will go back to sleep stage after time TA as show in Figure 6(b).

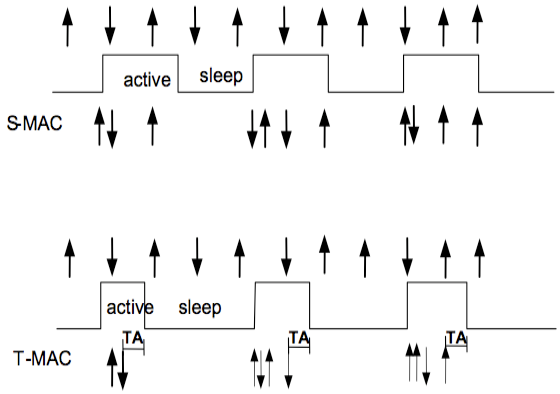

Figure.6 (a) (b)

If there is no active event, the choice of TA is critical for the performance of TMAC.
The following equation defines the minimum value of TA, as shown in Figure 7:

$$TA > C+T+R$$

Where, C= length of the contention time (interval), R= propagation time for RTS packet,
T= turn -around time (the short time between the end of the RTS packet & the beginning of the CTS packet).

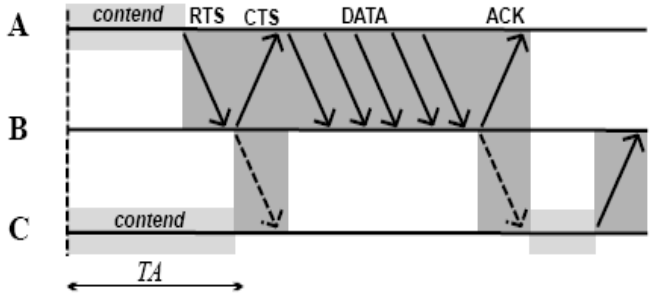

Figure.7

(D) Wireless Sensor MAC (Wise MAC) Protocol

It is work on the proactive network where network is work only after predefined interval of time. it is a protocol where all nodes in the network wake up periodically with defined period Tw, to check for any activity of the medium, as shown in Figure 8.

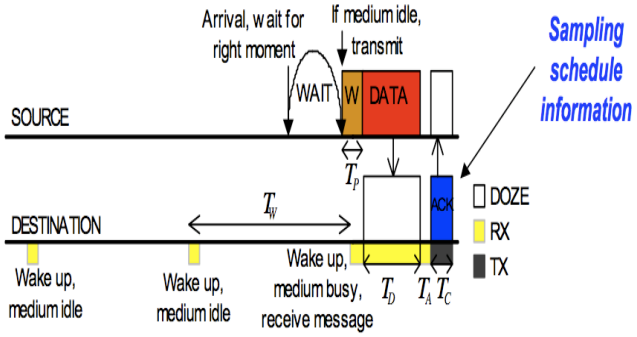

Figure 8

In this protocol, nodes are not synchronized to wake up simultaneously and due to this it reduces the synchronization overhead for the network. In the transmit and receiving node work for same time interval For example if receiving node turns on its radio for a short period (<Tw), the transmitting node should transmit along a signal of size equal to Tw for proper communication. [9]

V. Network Layer specifications and protocols

The network layer deal with the routing protocols for WSN. Routing protocols are divided in various categories. Network layer is considered the most complex layer. routing protocols used in WSNs have several features that can be make this possible for example the ability to deploy large number of sensors, limitation on power sources and more frequent changing the node location[10].
In this paper routing protocols for WSNs classified into two categories; each has its own subcategories as shown in Figure 9.

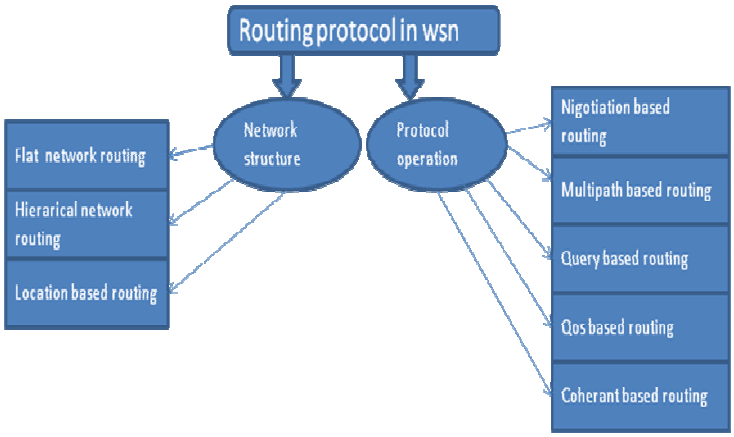

Figure 9

Flat Routing Protocols: Flooding and Gossiping

Flooding is a well-known technique used to broadcast information across a network. It is very simple, direct and easy to implement technique that could be used for routing in WSNs but it has severe disadvantages such as,

- Implosion: When duplicated messages are sent to the same node
- Overlap: When two or more nodes share the same observing region, they may sense the same event (phenomena) at the same time. As a result data redundancy occurs and neighboring nodes receive same messages from different nodes.
- Resource blindness: Does not concern the available energy resources.

Gossiping is a variation of flooding attempting to correct some of its disadvantages. Nodes not send message to all nodes in the network but instead send a packet to a randomly selected neighbor. The node receives the

packet and repeats the same process. Implement of the flooding mechanism is not simple approach and it takes longer time for the propagation of messages across the network. In Figure10, it shows the example of above concept. [10]

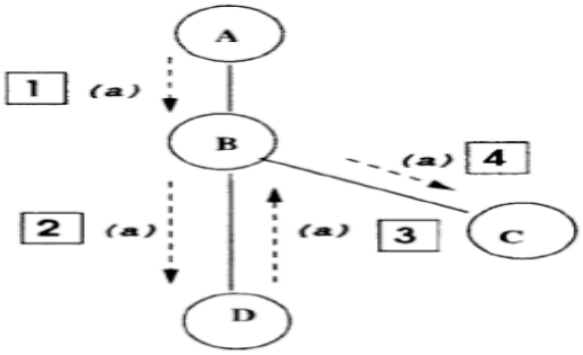

Figure 10

Hierarchical Routing Protocols: Low - Energy Adaptive Clustering Hierarchy (LEACH)

LEACH is a routing protocol designed for collecting and delivering it to the base station. Leach protocol is one of the hierarchical clustering routing protocols in WSN's. In LEACH protocol each node can become a cluster head, by which energy dissipation in each node can be relatively balanced. In LEACH time is divided into rounds, and in each round all the nodes comes forward to become cluster head according to a predefined criterion.

The main objectives of LEACH are as follows:

- expansion of the lifetime of node and network
- minimize utilization of energy of each node
- Use of data aggregation technique for data collection in cluster head for forward ahead.

To achieve these objectives, LEACH adopts a hierarchical designing, where the whole node and network is organized into clusters. Each cluster is having one node as a cluster head which managed and performs several tasks. Cluster Head collect the proactive (periodic) data from the other node of the cluster, aggregates it and also forwarding the aggregated data towards the base station where other cluster head also send the data as shown in Figure 11. [11]

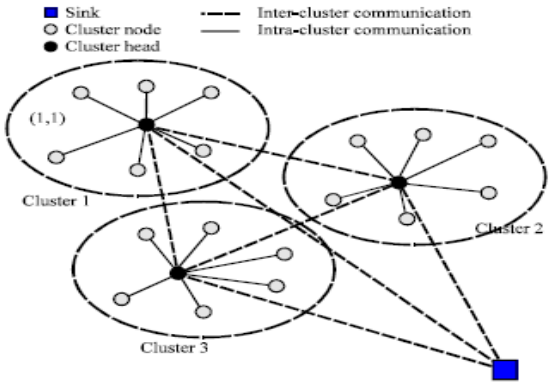

Figure 11

The other task of clustering algorithms is to assign a time slot for each member for transmission of data to cluster head. As shown below in figure 12.

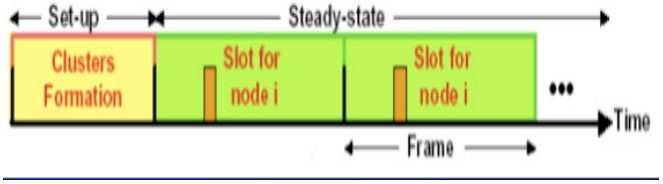

Figure 12

Location base Routing Protocol: Geographical Adaptive Fidelity (GAF)

GAF is a protocol which is GPS based algorithm design and used primary for mobile ad-hoc network. It can also be utilized in routing data in WSN. Geographic information is used to calculate the distance between two nodes in network. Sensing and transmitting Range is depends on node and distance between nodes is measure by GAF. The energy consumption is also depends on distance between nodes. GAF may also be considered as a hierarchical protocol. [11]

GAF goes through three states during operation Sleeping, Discovery and Active states. Firstly, node starts in discovery state and after Td, it broadcasts discovery message. After that, it enters into active state where it sets Timer Ta. Than node periodically re-broadcasts discovery message while it is in active state. Finally, after Ta, node returns to discovery state and active node can change to sleep state, if a higher-ranked node handles routing. A representative node is selected in each particular cluster to transmit the data to other nodes as show in Figure13. [11]

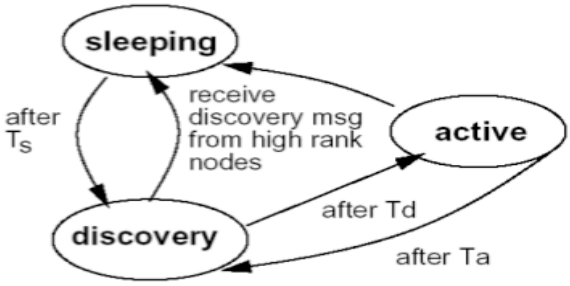

Figure 13

Here is a table no. 2 comparing the three previous routing protocols with its design factors.

protocols	Classification	Mobility	Position Awareness	Power Usage	Data Aggregation	Localization	Complexity	Multipath
Flooding & gossiping	Flat	Possible	No	Limited	Yes	No	Low	Yes
LEACH	Hierarchical	Fixed	No	Maximum	Yes	Yes	High	No
GAF	Location	Limited	No	Limited	No	No	Low	No

Table 2

VI. Conclusion

A lot of research has been carried out on improving the data and transport performance of data in WSN.

In this paper we are mainly focus on sensor node and sensor design factors. This paper also deal with important layers and its protocol used in WSN protocol stack WSN has bright future in the field of networking because it continuingly providing us solutions for many monitoring problems. Also we can conclude that to make the Wireless sensor network with energy efficient is always the important areas for future work.

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