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A Review of Routing Protocols for Underwater Wireless Sensor Networks

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Abstract: Underwater sensor network consists of number of various sensors and autonomous underwater vehicles deployed underwater to coordinate, interact and share information among themselves to carry out sensing and monitoring functions. Underwater sensor networks have wide range of applications like pollution monitoring, disaster preventions, assisted navigation, under sea explorations, advance military capabilities, mine reconnaissance etc. underwater sensor networks pose great challenge to our existing technologies used in terrestrial sensor network, because underwater environment differs from terrestrial radio environment both in terms of energy costs and channel propagation phenomena. In underwater sensor network, acoustic wireless communication is used in place of radio frequency and optical signal. Some of the issues in which underwater sensor network differ from terrestrial are limited bandwidth, battery power, failure of sensor nodes due to fouling and corrosion. Thus, design of routing protocols for underwater sensor networks pose many challenges due to intrinsic properties of underwater environment.

Keywords: underwater sensor networks, routing, depth based protocols, energy efficiency, acoustic communication.

1. INTRODUCTION

Wireless sensor networks have gained popularity in recent years due to recent advancements in Micro Electro Mechanical Systems (MEMS) [1][2], wireless communications and Digital electronics. These advancements have simplified the development of smart sensors such nodes have characteristics like low cost, low Power consuming, multifunctional, and small form factor. These nodes are equipped with data processing and communicating components like one or more sensors, processor, memory, power supply, radio and an actuator. These sensor nodes can sense, measure, collect the data from the environment and transmit the collected data. Before transmitting the collected data, the sensor nodes use their processing capability to locally carry out simple calculations and only transmit the required data by filtering the unnecessary data.

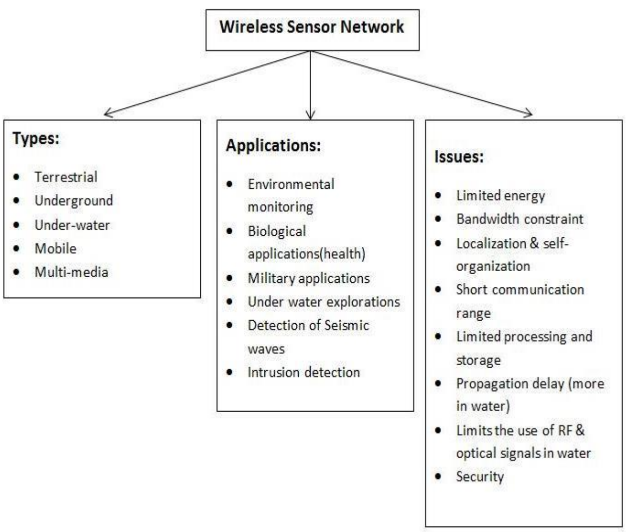

Figure1: Overview of wireless sensor networks

A wireless sensor network generally has little or no infrastructure. It consists of number of sensor nodes working collectively to monitor an area to obtain data about the environment. The sensor nodes can be deployed in adhoc manner or pre planned manner. In adhoc manner the sensor nodes are deployed randomly into the field and the network is then left unattended to perform monitoring. In predetermined or pre planned manner the fewer sensor nodes are placed at particular location to monitor the environment. In adhoc manner the network maintenance such as managing connectivity and detecting failures becomes difficult. In case of pre-planned deployment fewer nodes are deployed with lower network maintenance and management.

Wireless sensor networks have wide range of application areas like military, security, health, environment etc. In health the number of wireless sensor network based wearable physical monitoring system has been developed to monitor the health status of the patient remotely by a doctor. For example wearable Smart Vest which measures blood pressure, heart rate, body temperature etc. to monitor patients in an efficient manner and galvanic skin response (GSR) which measures the continuous variations in the electrical characteristics of skin has been developed. AMON(Advanced care and alert portable telemedical MONitor) wrist worn wearable monitoring system for high-risk cardiac or respiratory patients has been developed to monitor physiological parameters such as ECG, heart rate, blood pressure, skin temperature [3]. Further in military applications wireless sensor networks can be used for target tracking, the status of troops, the conditions and availability of equipment's in battle field. In environment wireless sensor can be used to detect the noise levels, temperature, humidity, pressure, forest fires, flood detection, water pollution and for seismic sensing.

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2. TYPES OF SENSOR NETWORKS

Wireless sensor networks can be categorized based on the environment of applications [2]:

Terrestrial Wireless Sensor Network: Terrestrial WSN consists of hundreds of sensor nodes deployed in either adhoc or pre-planned manner in a target area. In terrestrial WSN sensor nodes must be able to communicate the data effectively back to the base station. In terrestrial WSN battery power is limited, but the sensor nodes can be recharged from the solar energy.

Underground Wireless Sensor Network: Underground wireless sensor network consists of sensor nodes deployed underground in cave or mine to monitor underground conditions. Underground sensor networks require additional sink nodes that are located above ground to relay information to the base station.

Underwater Wireless Sensor Networks: Underwater sensor networks deployed under water. Here the nodes are more expensive in comparison to terrestrial and underground as nodes operate in harsh environment.

Mobile wireless sensor Networks: Mobile wireless sensor network consists of sensor networks that can move on their own and can sense the environment .A mobile wireless sensor network have ability to self-organize themselves.

In this paper we have focused on Under Water Wireless Sensor Networks

2.1 Underwater Sensor Network [2][4]

Underwater sensor networks consist of variable number of sensor nodes and Autonomous underwater vehicles deployed underwater. Sensor nodes are used to perform collaborative monitoring task over a given area in the underwater situations and Autonomous underwater vehicles are used for investigation or gathering data from the sensor nodes. Underwater sensor networks can be used for various applications like assisted navigation, oceanographic data collection, detection of pollution level , offshore activity examination, disaster prevention, and tactical observation and predict natural disturbances in the ocean. The ability of these network to monitor, investigate, and track underwater occurrences has increased an attention in building UWSN. The above mentioned features enable a broad range of applications for underwater sensor network.

Underwater sensor nodes and underwater vehicles must have self-configuration capabilities. Underwater sensor nodes may be relocated due to movement by the aqueous processes like advection and dispersion. After relocation by currents and dispersion, the sensor nodes must have the capability to reorganize as a network in order to maintain communication. For this participating sensor nodes should have extensive knowledge of network parameters prior to joining automatic configuration. They must have the capability to synchronize their operation by exchanging various parameters regarding configuration, location, and movement operation and to transmit monitored data to some on-shore station.

3. GENERAL ARCHITECTURE OF UNDERWATER SENOR NETWORK

Figure 1 describes the architecture of a Simple underwater sensor network. It consists of set of underwater water clusters (UW –LAN). Each sensor node is connected to the sink node (Gateway) within the cluster .The sensors can be connected to underwater sinks via directed paths by multiple hops. The data gathered by sensor nodes is transferred to the surface station by the sink nodes.

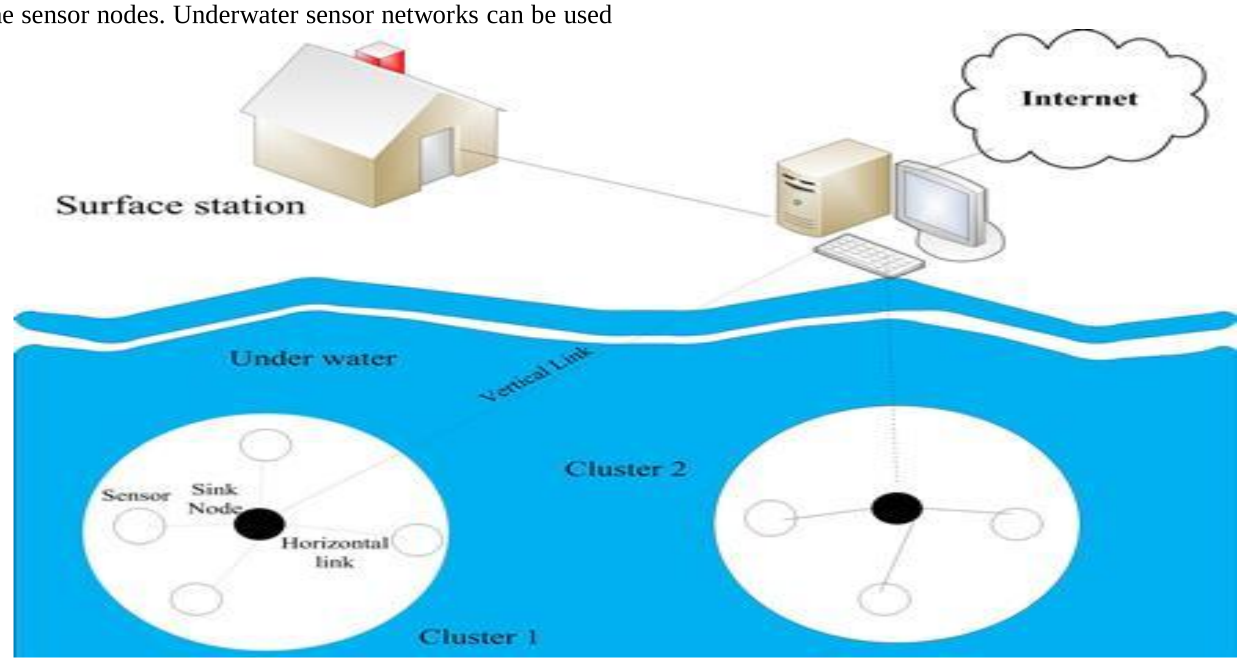

Figure 2: A typical Underwater Sensor Network

4. APPLICATIONS

The application of wireless sensor networks to the underwater domain has huge potential. They can be used for monitoring the health of the river and marine environments which on other hand is costly and difficult for humans. For manual monitoring sea divers are regulated in the hours and depths at which they can work and require boats on the surface that is costly to operate. Further manual operations are restricted by weather conditions. A sensor network deployed underwater could monitor the various physical parameters such as temperature, pressure, conductivity, turbidity, and certain pollutants [8]. The major applications of Under Water Sensor Networks (UWSN) are as follows.

• *Environmental monitoring:* UWSNs can perform pollution inspection such as chemical, biological and nuclear. It is also possible to use it to provide the detail of the chemical slurry (a suspension of insoluble particles) of antibiotics, estrogen-type hormones and insecticides. It can also be used for monitoring of ocean currents, winds, improved weather forecast, detecting climate change, biological monitoring such as tracking fishes and micro-organisms [4].

• *Disaster preventions:* UWSNs can measure seismic activity along the sea floor from remote locations and predict an approaching tsunami. This monitoring allows coastal areas to be notified and warned in time to prevent any disaster [4].

• *Assisted navigation:* sensors can be used to identify dangers on the seabed, locate hazardous rocks in deep water and submerged wrecks (Destroyed parts of ship due to accident)[4][8]

• *Under sea explorations* :Under water sensor networks can be used for detecting underwater oil fields or reservoirs, deciding route for laying underwater sea cables predict natural disturbance in the ocean and help in search of valued minerals [4][8].

• *Mine reconnaissance:* The simultaneous operation of multiple underwater acoustic vehicles with acoustic and optical sensors can be used to perform speedy environment assessment and detect items like mine [8].

• *Ocean sampling networks:* Network of sensors and underwater vehicles can be used to perform synoptic, cooperative, adaptive sampling of coastal ocean environment [8].

5. TRADITIONAL APPROACH OF UNDERWATER SENSOR DEPLOYMENT

The traditional approach was to deploy underwater sensors recording data during monitoring sessions and then taking the devices out to retrieve the data from the device. This approach has certain disadvantages as mentioned below

• *Lacks real time monitoring:* The recorded data was only accessed when the instrument was recovered. In certain situation the instrument was recovered after several months. This was critical especially for seismic monitoring.

• *Lacks online system reconfiguration:* There was no interaction between onshore station and monitoring instrument and it was not possible to reconfigure the system after particular event occurs.

• *Difficult to know status of device (sensor node):* If was not possible to known on onshore station whether the monitoring device has failed or it is working. It was only possible to know the status of the device when it was recovered from the environment.

• *Storage capacity:* The sensors have limited storage capacity so they can store limited amount of data during monitoring

The above are mentioned disadvantages of traditional approach forced to deploy underwater network that have the ability of real time monitoring, remote configuration and interaction with onshore station. This can only be possible to connect the underwater instruments by some means of wireless communication.

6. ISSUES IN THE DESIGN OF UNDERWATER NETWORKS

We cannot use RF and Optical signals in underwater sensor networks. The RF signal due to high attenuation and absorption effect in underwater environment is able to travel in water for only short distance. Radio waves can travel long distances in underwater, but at low frequency in the range of 30-300 HZ. This frequency range requires high transmission power and large antenna for its transmission [4], [6]. The problem associated with the use of optical signal is scattering. Further the transmission of optical signal requires very high precision in pointing the narrow laser beams as it requires line of sight communication [9]. Some of the major challenges associated with communication medias are listed as below:

• The bandwidth in underwater sensor is limited because bandwidth of underwater acoustic channel depends critically on transmission loss which increases with both range and frequency [4].

• Ray bending due to Snell' s law

• The underwater channel is several impaired especially due to multipath and fading [4].

• The propagation delay in underwater is much higher than in radio frequency terrestrial channel [4]

• The battery power is limited in underwater sensors and cannot be recharged because solar energy cannot be used in underwater [4].

• Sensor nodes in underwater are prone to failure due to fouling and corrosion [4].

• The majority of sensors may relocate with the current, therefore determining the sensor's location becomes one of the challenges [11].

• Underwater sensors are very costly due frequent and costly maintenance required [13].

In this paper we have described some of the methods proposed in literature for underwater communication. As already mentioned, radio frequency and optical signal cannot be used in underwater communication. In underwater communication acoustic wireless communication is used. Acoustic communication is defined as communication that uses acoustic signals from one point to another. It is difficult to use electromagnetic wave which can travel only short distance in underwater due to high attenuation and absorption effect. Acoustic waves have low absorption effect in underwater environment so they are used as a primary carrier for underwater wireless communication systems.

7. BASICS OF ACOUSTIC PROPAGATION

Propagation in underwater poses a major challenge for technologies that are currently used in terrestrial sensor networks. Acoustic waves used for underwater networks have lower losses in underwater than the radio waves. The lower loss of these waves makes them more suitable for underwater communication than radio waves. The speed of sound in water is around four times better than the speed of sound in air, but five times lesser than the speed of light. The critical factor that differentiates acoustic wave propagation from electromagnetic propagation is the low propagation speed of sound in water. The speed of sound in water depends on the various factors such as temperature, salinity and depth. The speed of sound increases in water with the increase in temperature, salinity as well as depth. Mostly, the change in the speed of sound is due to changes in temperature. However the effect of salinity on sound speed is small. Further, the salinity changes in the open ocean are normally negligible.

The change in the speed of sound near shore varies greatly due to more variation in salinity. Speed of sound is also affected by the increasing pressure with the increase in depth. The propagation speed of acoustic waves is five orders of magnitude slower than radio waves presenting greater challenge that must be overcome with algorithms, protocols and node placement [7, 9].

Underwater propagation is effected by several factors some of them are Path loss, Multipath propagation, High propagation delay, and Doppler effects .These factors make available bandwidth of underwater acoustic channel very limited. Underwater acoustic links are classified into different categories depending upon their range as very long, long, medium, short and very short [4]. Acoustic wave may also be classified as vertical and horizontal as per the direction of sound ray with respect to ocean bottom.

8. ROUTING IN UNDERWATER SENSOR NETWORK

Routing in underwater sensor network is challenging because of dynamic topology of nodes due to ocean currents, limited power, and long prorogation delay in acoustic communication.

Thus during the design of a routing protocol for sensor network we should consider the factors like long propagation delay, low communication bandwidth, dynamic topology and energy efficiency.

Several protocols has been designed for underwater sensor networks some of them are described below

8.1 VBF (VECTOR BASED FORWARDING) [10][12]

Vector based forwarding is location based routing protocol which is robust, scalable and energy efficient. In this protocol packet forwarding from source to destination is carried along redundant and interleaved paths thus making VBF robust against packet loss and node failure. In VBF each packet contains the three entities the position of sender (SP), the target (TP), and the forwarder (FP). In VBF source node computes a vector from itself to destination that specifies the forwarding path. Forwarding path is virtually a routing pipe from source to destination. Once a packet is received, the node computes its position with respect to the relay or forwarder node and if it realizes that it is close to the routing vector (virtual pipe) depending on fixed threshold distance, it puts its own computed position onto the packet and continues forwarding it. Alternatively, if it is not close enough to the routing vector, it just discards the packet. The nodes inside the routing pipe are eligible to forward packets, while the nodes that reside outside the routing pipe are ineligible to forward packets. However, the forwarding policy needs to be adjusted based on local node density in order to make efficient use of energy. VBF uses adaptation algorithm to adjust forwarding policy. When a node receives a packet it first computes its position and determines if it lies in routing pipe. If it lies in routing pipe then node holds the packet for a time interval $T_{adaptation}$ given below

$$T_{adaptation} = \sqrt{\alpha} * T_{Delay} + (R-d)/v_o$$

Where T_{Delay} is predefined maximum delay, v_o is the propagation speed of acoustic signal in water and d is the distance between this node and forwarder or relay node, R is transmission range.

8.2 DEPTH BASED ROUTING PROTOCOL (DBR) [11][12]

Depth based routing uses the multisink underwater sensor network architecture, where many sink nodes are usually situated at the water surface. In depth based routing, packet forwarding decisions are made locally based on the measured depth (or pressure level) at each node, so the packet is greedily forwarded to the node with lower depth among neighbors. To obtain depth, each node is suggested to equip with depth based sensor.

The DBR works as follows: when a node receives a data packet, it first retrieves the depth d_p of packet previous hop. The node then compares its depth d_c with the depth obtained from the packet i.e. d_p. If $d_c < d_p$ i.e. nodes is closer to the water surface then it considers itself as a qualified node to forward data packet, otherwise the packet is discarded because the packet came from the node which is closer to the surface. In DBR multiple neighboring nodes of a forwarding node are qualified to forward packets to the next hop. In DBR protocol there may be high collision and energy consumption if all the nodes broadcast the packet and in order to reduce collision and energy consumption, the number of forwarding nodes should be controlled. The problem in DBR routing is redundant packets, which occur in two ways: due to multiple paths used to forward packet and the other is that node may send a packet many times repeatedly. Thus, to save the energy redundant packets need to be suppressed. DBR uses the idea of a priority queue Q1 to reduce number of forwarding nodes and packet history buffer Q2 to ensure that nodes forwards the same packet only once in certain time interval.

8.3 DISTRIBUTED UNDERWATER CLUSTERING SCHEME [12][15] (DUCS)

Many hierarchical or cluster based routing protocols such as TEEN (Threshold sensitive Energy Efficient sensor Network protocol) [13] and PEGASIS (Power Efficient Gathering in Sensor Information Systems) [14] were proposed for terrestrial sensor networks to improve the scalability, lifetime and energy efficiency of the network. But these are not suitable for underwater sensor networks as they assume the sensor nodes are stationary. Further, these proposed schemes are not well adapted to properties of underwater environment such as propagation delay, low bandwidth and energy constraints.

DUCS is a GPS free routing protocol. It assumes Multihop routing between clusters and an energy aware cluster head selection algorithm. DUCS is adaptive self-organizing protocol, where the formation of clusters is done with the help of distributed algorithm. In DUCS sensor nodes are organized into clusters and one node is selected as a cluster head. All the nodes send data to their respective cluster head, whose responsibility is to perform signal processing functions to remove redundant data before transmitting data to sink in order to save the energy. DUCS includes randomized rotation by choosing different cluster-heads among the sensors to avoid fast draining of battery of any underwater sensor node in the network. DUCS operation is divided into two rounds: one is cluster setup or cluster creation process, where the cluster head is chosen and second is network operation phase, where data transfer occurs. A node initially sets its probability to become cluster by using following formula

$$CH_{prob} = C_i / C_{Max}$$

Where C_i represents the node's battery level and C_{Max} represent the maximum battery capacity, C_{prob} is small constant fraction used to set initial probability percentage of cluster heads in order to limit the number of cluster head announcements

8.4 HOP BY HOP DYNAMIC ADDRESSING BASED ROUTING PROTOCOL (H^2-DAB) [12] [17]

Routing protocols like VBF [10] and Localization Scheme for Underwater Wireless Sensor Networks [16] require full dimensional location information of nodes, which is another issue in underwater sensor network needs to be solved. H^{2-}DAB based on multilink architecture is robust, scalable and energy efficient. The major achievements of hop by hop dynamic addressing based routing protocol is to improve the delivery ratio, optimize energy consumption and minimize the message latency. The purpose of H^2-DAB is to solve the node mobility problem caused by water currents. In order to solve node mobility problem the H^2-DAB uses dynamic addresses, so that sensor nodes will get new addresses according at different depth intervals. H^{2-}DAB completes its job in two phases. First phase creates the routes by assigning dynamic addresses and the second phase forwards the data by using these addresses.

8.5 LOW PROPAGATION DELAY MULTIPATH ROUTING PROTOCOL (MPR) [18]

This protocol was proposed to increase the efficiency, network lifetime and scalability in underwater sensor networks. In this protocol all the nodes send data to surface sink when they detect some underwater occurrences. In this protocol data packet at source node is divided into several time slots based on the bandwidth and a two hop transmissions is used to transmit data packet to relay nodes which transmit the data to the destination. Before transmitting data, relay nodes check transmission scheduling to detect collision. In case of collision, the relay nodes defers for the appropriate time slots to avoid collision. The main aim of multipath propagation is to reduce the propagation delay.

In this protocol multiple paths are used to transmit the data from source to destination. There are two advantages of multipath: packet drop rate is decreased because load is distributed across multiple paths, and high network robustness is achieved. In MPR protocol, multi-path transmission is used by source, relay and destination node. The MPR protocol consists of three phases: (1) Propagation delay collection phase (2) Intermediate node selection phase (3) Relay node selection phase

8.6 DEPTH CONTROLLED ROUTING PROTOCOL (DCR) [19]

Depth control routing protocol is a geographic routing protocol with network topology control. To overcome the problem of void node or local minimum this protocol adjusts the depth of some nodes in order to establish the network topology and forward data where greedy geographic routing protocol fails. It is the first geographic routing protocol that has ability to consider the vertical movement of sensor nodes to improve network connectivity and delivery rate. In greedy forwarding strategy, when a node has a data to send, it selects the next neighbor as a next hop which is closest to destination and then forwards packet to them. This procedure continues until the data reaches final destination. This protocol provides centralized algorithm to determine the set of nodes that cannot reach destination through multihop communication and calculating new depth to them. This protocol has two phase one is network initialization phase other is network operation phase.

Table1: Characteristics of some underwater routing protocols proposed

Protocol	Characteristics
VBF	Better end to end delay, Robust, Energy efficient, handles node mobility effectively, Based on assumption that node location is known. Not good for dense networks

DBR	DBR with multiple-sinks achieves a better packet delivery ratio and best end to end delay than DBR with one-sink. Requires more memory for Priority queue Q1,Packet history buffer Q2. Does not need full dimensional location information of sensor nodes. Energy efficient consumes half energy than VBF . It is not good for sparse networks. Low communication cost
DUCS	DUCS achieves very high packet delivery ratios in small and large network sizes. Minimize data loss, reduces the network overhead and increases throughput consequently. Energy efficient and scalable. Compensates high propagation delay of the underwater medium. Due to frequent breakdown of cluster causes burden on network.
H^2-DAB	Handles node mobility , no need to maintain complex routing tables. Provides good delivery ratios with improved control on energy consumption with scalability
MPR	High packet delivery ratio in dense(having more nodes) networks. Reduces transmission and propagation delay. Load balancing is achieved because date is distributed over multiple paths. Increase battery lifetime
DCR	More energy consumption than DBR in lower density networks. Avoid void nodes. Topology control. Higher delivery ratio than DBR

9. CONCLUSION

In this paper, we have presented applications, challenges and issues in the underwater sensor networks. Routing in UWSN is an important issue as underwater channel characteristics are concerned, thus attracting significant attention from the researchers. The design of any routing protocol depends on the goals and requirements of the application as well as suitability, which depend on the availability of network resources. In this regard we have compared some previously proposed routing protocols for underwater sensor network, where we concluded that there are certain advantages as well as some disadvantages in every protocol we mentioned. Keeping in mind the routing issues and challenges for underwater sensor network and the disadvantages of previously proposed protocols, some new algorithm can be proposed providing an efficient routing protocol for UWSN meeting all the challenges in future. The development of routing techniques suitable for underwater environment is therefore regarded as a developing research area, which will make these networks much more reliable and efficient.

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