Assignment 1

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Question1

- *IEEE 802.15.4* defines operations of physical layer (PHY) and data-link layer (MAC) in low-rate wireless personal area networks (LR-WPANs).

  Standard: The protocol and compatible interconnection for data communication devices using low data-rate, low-power, and low-complexity short-range radio frequency transmissions in a wireless personal area network (WPAN) are defined in this standard.

  Data Rate: In the original version, data rate are 20 kbits/s and 40 kbits/s in the 868/915 MHz bands. In the 2450 MHz band, data rate is 250 kbits/s. In 2006 revision, 868/915 MHz bands can support 100 kbits/s and 250 kbits/s.

  Range:10 meters communication.

  Frequency Band: The original 2003 version, the frequency bands are 868/915 MHz bands and 2450 MHz band. The *IEEE 802.15.4c* study group considered the newly opened 314–316 MHz, 430–434 MHz, and 779–787 MHz bands in China, while the *IEEE 802.15.4d* supports the new 950–956 MHz band in Japan.

  Topology: Star topology and Peer-to-Peer network topology.

  Power Requirement: Low power consumption of sensors is one of the key elements of *IEEE 802.15.4*.

- *IEEE 802.11 AH* belongs to PHY and MAC.

  Standard: The *IEEE 802.11 AH* standard is aimed at providing a global Wireless LANstandard that operates within the unlicensed Industrial, Scientific, and Medical (ISM), bands that are available below 1 GHz. In this way *IEEE 802.11 AH* will allow Wi-Fi-enabled devices to gain access for short-term transmissions in these frequency bands that are currently much less congested.

  Data Rate: The transfer rates depend on the number of spatial streams, modulation type, channel, and guard interval (time between symbols). The maximum data rate of

Modulation type	Coding rate	8 μs GI	4 μs GI
BPSK	1/2	5.85	6.5
QPSK	1/2	11.7	13.0
QPSK	3/4	17.6	19.5
16-QAM	1/2	23.4	26.0
64-QAM	2/3	46.8	52.0
256-QAM	3/4	70.2	78.0

Table 1: Date rates (in Mbits/s) with 1 spatial stream and using 16 MHz channels in different modulation types, coding rates, and guard interval (GI)

Country	Frequency band (MHz)
China	755 - 787
USA	902 - 928
Europe	863 - 868
Japan	916.5 - 927.5
Korea	917.5 - 923.5
Singapore	866 - 869 / 920 - 925

Table 2: Available frequency bands in different countries

IEEE 802.11 AH is up to 347 Mbits/s with four spatial streams and using a 16 MHz channel with 4 μs guard interval. The minimum data rate of this standard is down to 0.3 Mbits/s with one spatial stream and using 1 MHz channel with 8 μs guard interval. Some data rates is shown in the Table 1.

Range: Wider coverage range than Bluetooth, which means longer than 10 meters.

Frequency Band: Different countries have different available unlicensed ISM bands. Table 3 some available frequency bands and corresponding country.

Tozpology: Star topology and tree topology.

Power requirement: This standard require low power consumption of sensors.

- *Wireless HART* defines operations of Physical layer, Data link layer,Network layer,Transport layer,Application layer

Standard: Wireless HART is a secure TDMA-based(10 ms time slot) wireless mesh network protocol, working in the 2.4GHz ISM(Industry Science Medicine) band, using DSSS(direct-sequence spread spectrum) technology and FHSS(Frequency-Hopping Spread Spectrum)technology.

Data Rate: Wireless HART is mainly based on the IEEE 802.15.4-2006 which means the data rate could be up to 250 kbits/s.

Range: Depending on local units of measurement, the rule of thumb distance for the standard antenna is 225 meters or 750 feet with -75dB and 100 meters with 0dB loss.

Frequency Band: Wireless HART works on the 2.4GHz which is between 2400-2483.5MHz.

Topology: Wireless HART supports both star and mesh topology.

Power requirement: Wireless HART consume at less than 50A per node and is mainly battery-powered

- **Bluetooth Low Energy BLE:**The type of architecture has some difference among above three protocols. The architecture of BLE could be mainly divided into three parts,Application layer which is similar to that of IoT stack, host layer which is a high level layer of the protocol stack including GAP(Generic Access Profile) and GATT(Generic Attribute Profile), and Controller layer which includes Physical Layer(similar to that of IoT stack) and Link Layer.

  Standard:BLE is designed by the Bluetooth Special Interest Group(Bluetooth SIG) and is mainly based on IEEE 802.15.1. It is distinct from the Bluetooth Basic Rate/Enhanced Data Rate protocol which means they have no compatibility but could coexist.

  Data Rate: The BLE radio transmits 125 Kb/s to 2 Mb/s

  Range: The theoretical max range of BLE is around 50 m (160 ft)

  Frequency Band::BLE works on 2.4GHz ISM band and divided this band into 40 channels on 2 MHz spacing from 2.400GHz to 2.4835 GHz,starting at 2402 MHz.

  Topology: The BLE uses a Star-bus topology which means each slave nodes communicate on a separate physical channel with the master node.

  Power Requirement: The device consume 0.01–0.50 W

  Other Characteristics:Before applying to the carrier frequency, the data pulses are filtered with a Gaussian filter which could make the signal more smooth. In order to co-exist with 802.11/Wi-Fi, BLE have been assigned center frequencies to minimize overlapping with most 802.11 channels.

- *LTE-A:*LTE-A has Physical layer like most protocols, and Data link layer which consist of MAC, RLC(radio link control) and PDCP(Packet Data Convergence Protocol) and Network Layer which consists of RRC(Radio Resource Control). Besides those, LTE-A also has a NAS protocol.The non-access stratum (NAS) protocols form the highest stratum of the control plane between the user equipment (UE) and MME.

  Standard:LTE-A is the enhancement of the LTE standard which means it improved on the basis of LTE protocol.

  Data Rate: The peak rate of Downlink speed could be up to 1 Gbps, the peak rate of Uplink speed could be up to 500 Mbps and the latency could be less than 5 ms.

  Range:The range of LTE-A varies according to different scenarios.The key to define the range is called preamble formats. Different preamble formats used in different situations. For example, In the community where we live in,the preamble format 0 is used and the range could be up to 14 km which is not too far. However, if we use format 3, the range could be up to 100 km which could be applied in remote areas such as deserts and forests.

  Frequency Band: The frequency Band of LTE-A is different from above protocols which work in 2.4 GHz. Different countries use different frequency bands. For example, in Europe it could use 800,900,1800,2100 and 2600 MHz Frequency, in Canada and US,it works on 700,850 MHz,1.7/2.1,1.9 and 2.5GHz, etc.

  Topology:LTE-A uses an advanced networks topology.

  Power Requirement:Low power consumption compared with LTE

- *Wi-Fi:*Wi-Fi has Physical Layer, Data Link Layer(MAC Layer and LLC Layer), Network Layer, Transport Layer and Application Layer.

  Standard: Wi-Fi is a family of wireless networking technologies which is based on the IEEE 802.11 family of standards.

  Data Rate and Band Frequency802.11 is a family of standards, therefore different child protocol has different data rates and works on different frequency band. The relationship among these are showing as follow.

  Range: The Wi-Fi works on 2.4Ghz or 5Ghz,which has different range. For those operating on the 2.4Ghz band can reach up to 150 feet indoors and 300 feet outdoors. For 5Ghz, the range only reached approximately one-third of these distances which 50 feet indoors and 100 feet outdoors.

Protocol	Frequency band (MHz)	Channel Width	Maximum data rate (theoretical)
802.11ax	2.4 or 5GHz	20,40,80,160MHz	2.4 Gbps
802.11ac wave2	5GHz	20,40,80,160MHz	1.73 Gbps
802.11ac wave1	5GHz	20,40,80MHz	866.7 Mbps
802.11n	2.4 or 5GHz	20,40MHz	450 Mbps
802.11g	2.4GHz	20MHz	54 Mbps
802.11a	5GHz	20MHz	54 Mbps
802.11b	2.4GHz	20MHz	11 Mbps
Legacy 802.11	2.4GHz	20MHz	2 Mbps

Table 3: Different Wi-Fi Protocols and Data Rates

Topology: Wi-Fi use two logic topologies: star topology(generally) and Point-to-point topology(in the ad hoc mode).

Power Requirement: Wi-Fi Router is the most common appliance in the house and usually it works 24/7. Therefore the consumption should be very low. It is estimated that a Wi-Fi router uses 2 to 20 watts, with 6 watts being average for a wireless router.

Question2

The MAC protocols of IEEE 802.11 standard could be used in sensor network but may not for a very constrained devices.
IEEE 802.11 standard use CSMA/CA as its MAC protocol. CSMA/CA refers to Carrier Sense multiple Access with Collision Avoidance and it is a contention-based protocol. The main mechanism is that before a node transmitting data, it will detect whether there exists a carrier in the same channel. If it does not, which means the channel is free and the node will directly transform to the data transmission state.If it does, it will wait for a period of time(through an algorithm) and then detect again until there is no carrier in the same channel.
CSMA/CA could be used for a sensor network since it could make the nodes communicate efficiently and avoid the collision. However,it could not be suitable for a very constrained devices.The reason are listed as follow. Firstly, as mentioned before the main principle of CSMA/CA is make the node to listen the channel before transmitting, if the channel is always busy which means the node should keep listening the channel for a long time.In that way,the node will consumes a lot of energy on listening rather than transmitting or receiving data. Secondly,the principle of collision avoidance is that if the channel is not free, the node will wait for a period of time which computed by an algorithm. For a very constrained devices, the ability of CPU may be not good enough to computer it and also it will consume some energy. In conclusion, the CSMA/CA could be used in sensor network only if the nodes are powerful enough.

Question3

Question4

- **Directed Diffusion:**
  Directed Diffusion route is a typical "Data-centric" routing.The main principle is the data generated by the sensor nodes is named by attribute-value pairs.When the sink request some data,it will send a interest and floods it through all network.The nodes that have the data which matching the Interests will send the data to the Sink on the reverse path of the Interests. Therefore, the DD routing could be divided in three processes, propagate Interest,setup the initial gradient and data delivery along reinforced the path.
  Pros.1) the sink will only receive the data which it is interested in and will be only once which greatly reduce the transmission of redundant information and save network energy.2Through a reinforcement path will increase the transmission rate. 3) The sink floods interests only if necessary,so it save lots energy. 4) For it is "Data centric",all communications are neighbor to neighbor with no need for a node addressing mechanism and each node could do aggregation and caching.
  Cons.1)It is not suitable for applications which require continuous data delivery ,e.g., environmment monitoring 2)Each node has to establish its own interest table and matching data to queries might require some extra overhead.

- **Rumor routing:**
  Rumor routing could be seem as a variation of Directed Diffusion. Compared with the directed diffusion protocol,it doesn't flood both interests and queries.The sensor node in the event area will produce the agent information and unicast along a random path. At the mean time, the request information which sent by the sink node also unicast along a random path among the network. When agent information and the quest information intersect, a complete path from the sink node to the event area will be formed.
  Pros.1) Compared with the Directed Diffusion,the Rumor routing only maintain one path from the sink to the source node,so it doesn't need to reinforcement the path which could greatly decrease the consumption of energy.2)We can use some methods to tune the best effort delivery,e.g,create a set of straight line gradients from events,then sending query along a random straight line from the sink.3)The range of query/event ratios are tunable.
  Cons.:1) Both path from event and sink are random so it could not guarantee the path is the optimal and may exist the loop.2) For a large number of events, the cost of maintaining the event table and processing agents will increase dramatically.

- **LEACH**
  LEACH(Low Energy Adaptive Clustering Hierarchy) is different among above 2 protocol. It is a hierarchical architecture routing protocol. For hierarchical architecture, the cluster heads will be randomly rotated among the sensors and all non-cluster head nodes transmit data to their cluster head. CH receives this data and performs signal processing funtions on the data and transmits data to the BS. There will be three

processes for LEACH Protocol,select the Cluster Head,Cluster Formation,steady State Phase.There is an algorithm to select the Cluster Head in order to ensure that each node will be Cluster Head once in all rounds. The cluster heads using CSMA MAC protocol to broadcasts its advertisement message and the each non-Cluster Head transmits a join-request message back to the Cluster head which it chosen using a CSMA MAC protocol. Then the Cluster Head set up a time schedule according to the TDMA protocol and sent it to the non-cluster nodes within the cluster. *Pros.:*1) The cluster heads are randomly selected,each node could be the cluster heads so that the energy consumption is divided equally among all nodes, and the network load is relatively balanced.2)Because it is a hierarchical architecture, the node within the cluster doesn't need to storage the information of routing which simplify the choice of the path of routing.3) The cluster head have the ability of data fusion which reduces the volume of transmitted information. *Cons.:*1)The cluster heads are randomly selected,so the cluster head nodes may be too concentrated or scattered at the edge of the network, resulting in uneven energy consumption of the network nodes, and some nodes die prematurely.2)if there are too many rounds to select the cluster head, the phase of setting up will consume a lot of consumption. 3) The leach protocol assumes that the energy of each node are uniform.If the initial energy of the entire network is not uniform,it will result some nodes stop working for lack of energy.

Question5

For a long time, the researchers have been discussing the energy consumption for static nodes of wireless sensor networks (WSN). Muhammad et al. conducted a study entitled "Multi-level Dynamic Optimization of Intelligent LEACH with Cost Effective Deep Belief Network," as a result of which they proposed a modified LEACH algorithm. After evaluating found out that the algorithm decreased the overall energy consumption and increased throughput. This article first reviews some basic background information on WSN. The scalability is the reason for clustering based routing protocols became popular. One example of the clustering-based routing protocols is the LEACH protocol. For LEACH protocol, the ability data aggregation and data fusion of cluster head became the main factors that reducing energy consumption and enhancing the network's lifetime. Therefore, the LEACH EEE protocol was used as a contrast measure for evaluating.

On the basis of retaining the advantages of LEACH protocol, they modified the network topology into centralized CH-Sink node hierarchy and distributed intra-cluster hierarchy two levels. The algorithm keeps the following steps: Sink node from base station first calculates the distance by broadcasting and receiving the message to all nodes. Secondly, in the start-up phase, the Voronoi Tessellation algorithm is used to establish the optimized cluster boundaries which provide the smallest energy consumption and the biggest the radius of each cluster. If the number generated by the sink node is larger than a threshold, then the sink node will wait for the next champian; otherwise, cluster heads will re-selected using the intracluster available energy resources. After cluster head randomly selected, the Voronoi Tessellation algorithm is used to reformulate cluster boundaries again. Then, the chosen cluster heads will use the ant colony optimization algorithm to find the best path to the base station. Finally, the cluster sends data to the base station. In the intra-cluster level, they abstracted the distributed intracluster routing as a strongly connected graph and used the smallest complexities algorithm to implement. The deep belief network with 3 hidden layers and online Gibbs sampling is used to monitor the two clustering techniques. Besides, iBRICH is used to minimize the noise data.

In their evaluation phase, Muhammad et al. established a network consist of 200 nodes and 20 nodes should be selected as cluster heads. Compared to the LEACH-EEE protocol, the throughput is about 6 times greater and the network lifetime is longer. For the intracluster level, the performance of iBRICH algorithm grater than the EM, Farthest First, Density-based, OPTICS and simple K- means, and the error rate is only 5

In conclusion, the article indicates that the modified LEACH algorithm which including uses the Voronoi tessellations to optimize the cluster boundaries and ant colony optimization to optimize the cost path from cluster head to sink node. After evaluating, the result shows that the algorithm could minimize energy consumption and increase throughput.