ECE 659/493: IOT Signal Processing and Intelligent Sensor Networks

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Q-1) For each one of the following IoT protocols determine to what layer of the IoT stack it belongs to, and describe its characteristics wrt: standard, data rate, range, frequency band, topology, and power requirements.

A) IEEE 802.15.4

- Layer – Physical Layer & MAC Layer
- Standard – IEEE 802.15.4
- Data Rate – 250 k bit/s in 2.4 GHz, 20 k bit/s in 868 MHz, 40 k bit/s in 915 MHz
- Range – 10m – 100m in 2.4 GHz
- Frequency band – 868 MHz, 915 MHz, 2.4 GHz
- Topology – Multi-hop topology (Star, Cluster-tree, and Peer to Peer Topology)
- Power Requirements – 0.5 mW to 100 mW or -3dBm to 20 dbm

B) IEEE 802.11 AH

- Layer – Combination of Physical and MAC Layer
- Standard – IEEE 802.11 AH
- Data Rate – 0.15-4 M bit/s if BW is 1MHz, 0.65-7.8 M bit/s if BW is 2 MHz
- Range – 100-1000m, Its Range is up to 1 km in outdoor areas
- Frequency Band – The frequency Bands are below or less than 1 GHz. They vary from country to country for eg: 863 – 86806 MHz in Europe, 902-928 MHz in America, etc.
- Topology – Single-hop topology (Star and Tree Topology)
- Power Requirements – Maximum 100 mW

C) WirelessHART

- Layer – Comprises Physical, Data link, Network, Transport, and Application Layer
- Standard – IEEE 802.15.4
- Data Rate – 250 k bit/s
- Range –Range for indoors is 50-100m and its line of sight or outdoor range is 250 m.
- Frequency Band – 2.4 GHz band
- Topology – It uses a flexible ad-hoc Mesh Network in which all devices in the field form a network.
- Power Requirements – It has one of the lowest power requirements in the industry which is less than 50 uA per node. It has variable transmit power with 10 mW in default

D) Bluetooth Low Energy BLE

- Layer – Physical Layer & link Layer
- Standard – IEEE.802.15.1

- Data Range – 125 k bit/s – 2 M bit/s
- Range – 160 m for 0dbm of transmission power, 295 m for 10dbm
- Frequency band – 2.4 G HZ ISM Band (2.402-2.48 G Hz)
- Topology – Followings are the role of devices used in BLE topology
  1) Advertiser : A device that broadcasts advertisement packets, but is unable to receive advertisement packets. It can allow or disallow connections.
  2) Scanner : A device that only listens for advertisements. It can connect to an advertiser.
  3) Slave : A device connected to a single master (BT 4.0) or multiple masters (BT 4.1 and newer).
  4) Master : A device that is connected to one or more slaves. Theoretically, a master can have an unlimited number of slave devices connected to it, but in reality, the master can connect 4-20 slaves at the same time.
  5) Hybrid : It is possible for a device to advertise and scan at the same time or be connected to a master and advertise or scan simultaneously. This is vendor-specific, and the exact features which are supported should be checked with the vendor.
- Power Requirements – Transmission power : 0.01 mW - 100 mW,

E) LTE-A

- Layer – Physical Layer & MAC Layer
- Standard – None
- Data Range – 3 M bit/s – 100 M bit/s
- Range – 10 miles
- Frequency Band – It shares the same frequency band with the first released LTE which has 2110-2170 M Hz for downlink and 1920 – 1980 M Hz for uplink. The most popular frequency band for it is 1800 M Hz
- Topology – It uses optimized heterogeneous networks with a mix of macros with low power nodes (picocells, femtocells, new relay nodes)
- Power Requirements – 43dBm

F) Wifi

- Layer – Network Layer & Application Layer
- Standard – Combination of 802.11a and 802.11b
- Data Range – 54 M bit/s
- Range – It reaches 46m indoors and 92m outdoors when it is operating on 2.4 G Hz. If it operates on 5 G Hz, the range will be reduced by one-third to the distances of 2.4 G Hz.
- Frequency Band – 2.4 G Hz or 5 G Hz
- Topology – It uses star topology which is a network topology that each network component is connected to a central node
- Power Requirements – 100mW in 2.4 GHz

Q-2) Can the MAC protocols of the IEEE 802.11 standard be used in IoT networks that run on very constrained devices. Justify your answer.

Answer:-

- In IEEE 802 reference model, the Data link layer is divided into 2 parts :
    A) Logical Layer
    B) MAC Layer
- The main function of the MAC Layer is to check the connectivity and transmission of a message between nodes by using contention-free or contention-based protocols.
- The constrained devices have restrictions on power consumption, so using IEEE 802.11 MAC Protocol here would be beneficial as the MAC layer allows nodes to switch between sleep and awake state, which means Communication happens when both nodes are awake. A lot of power is saved when nodes are in sleep mode.
- MAC Layer provides reliable data delivery which can help IoT networks on constrained devices as they have high packet loss and low throughput.
- So, yes MAC Protocol of IEEE 802.11 standard can be used in IoT networks that run on very constrained devices.
- Some other advantages of this are: Mac Protocol has higher throughput which leads to faster transmissibility of message (machine can turn off soon) and saves energy.

Q-3) In a data link layer the flow control is performed using the Stop and Wait protocol, if you are to define the minimum frame size to ensure 50% channel utilization show how to define this number. For the data rate use 8Kbps and the propagation delay is 100 msec.

Solution-:

Given

- Data rate = Bandwidth = 8Kbps
- propagation delay (T_p) = 100msec
- Channel utilization = Efficiency = 50%

Let required frame size = L bits

Transmission delay (T_d) = $\frac{Packet\ Size}{Bandwidth}$ = $\frac{frame\ Size}{Bandwidth}$ = $\frac{L\ bits}{8\ Kbps}$

Efficiency = $\frac{Td}{Td+2Tp}$ = $\frac{1}{1+2\frac{Tp}{Td}}$

50% = $\frac{1}{1+2\frac{Tp}{Td}}$

$\frac{50}{100}$ = $\frac{1}{1+2\times\frac{100\times10^{-3}}{\frac{L}{8\times10^{3}}}}$ = $\frac{1}{1+2\times\frac{800}{L}}$

$\frac{1}{2}$ = $\frac{1}{1+2\times\frac{800}{L}}$

$1 + 2 \times \frac{800}{L}$ = 2

$2 \times \frac{800}{L}$ = 1

L = 1600 bits

Q-4) For this question, use the OMNET++ simulation. Carry out a simulation for a an IoT network made of 25 hosts deployed in a simulation area of 500m * 500 m rectangular region for 900s simulation time using the AODV routing algorithm. Use the IEEE 802.11 as the MAC Layer in the simulation with the data
rate 11Mbps. The traffic source is CBR source, the sending rate is 3 packets/sec and the packet size is 512 bytes.
Perform number of simulations using the listed scenarios:

- **Use at least two different mobility models (e.g. Random Walk, Random Waypoint)**
- **Use mobility node speed that changes from 1m/s to 20m/s**

Measure and plot the following parameters (Packet delivery ratio, latency, throughput) vs. the node(s) speed for each mobility model.

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Below is the Specifications setup according to the question given:

```
[Config Wireless01]
description = Two hosts communicating wirelessly
network = Assignwireless
sim-time-limit = 900s      #(simulation time limit = 900s given in question)

*.host*.ipv4.arp.typename = "GlobalArp"

**.constraintAreaMinX = 0m
**.constraintAreaMinY = 0m
**.constraintAreaMaxX = 500m
**.constraintAreaMaxY = 500m
**.constraintAreaMinZ = 0m
**.constraintAreaMaxZ = 0m
#keeping Max value of x and Y  = 500 m

*.hostS.numApps = 1
*.hostS.app[0].typename = "UdpBasicApp"
*.hostS.app[0].destAddresses = "hostD"
*.hostS.app[0].destPort = 5000
*.hostS.app[0].messageLength = 512B         #(Packet size = 512 bytes given in question)
*.hostS.app[0].sendInterval = 0.5s
*.hostS.app[0].packetName = "UDPData"
*.hostS.wlan[0].radio.displayCommunicationRange = true       #keeping communication range display on

*.hostD.numApps = 1
*.hostD.app[0].typename = "UdpSink"
*.hostD.app[0].localPort = 5000

*.host*.wlan[0].typename = "AckingWirelessInterface"
.host.wlan[0].mac.typename = "Ieee80211Mac"
*.host*.wlan[0].mac.useAck = true
*.host*.wlan[0].mac.fullDuplex = true
*.host*.wlan[0].radio.transmitter.communicationRange = 250m
.host.wlan[0].radio.transmitter.interferenceRange = 0m
.host.wlan[0].radio.transmitter.detectionRange = 0m
*.host*.wlan[0].radio.receiver.ignoreInterference = true
*.host*.wlan[0].mac.headerLength = 23B
.host.wlan[0].radio.typename = "UnitDiskRadio"
*.host*.**.bitrate = 11Mbps                    # data rate is 11mbps (given in question)

#---------------------------------------------------------------------------
```

WirelessA.ned omnetpp.ini

```
#------------------------------------------------------------------------------

[Config Wireless02]
description = Adding more nodes and decreasing the communication range
extends = Wireless01

*.host*.wlan[0].radio.transmitter.communicationRange = 250m

*.hostS.wlan[0].radio.displayCommunicationRange = true

```

We are asked to use two mobility:

1) *Linear Mobility*: It is the motion in a linear form with the same speed or acceleration throughout. It's parameters include acceleration, speed and angle. The code used for linear mobility is as follows:-

```
#------------------------------------------------------------------------------
[Config Wireless03]
#linear Mobility
description = Configuring node movements
extends = Wireless02

*.hostA*.mobility.typename = "LinearMobility"
*.hostA*.mobility.speed = ${speed = 1 .. 20 step 1}mps        # keeping speed from 1 to 20 m/s given in question
*.hostA*.mobility.initialMovementHeading = 270deg

*.host*.wlan[0].queue.packetCapacity = 10         # queue is 10 so that node can hold next 10 datas coming from other nodes while transmitting one

*.visualizer.mobilityVisualizer.displayVelocities = true
*.visualizer.mobilityVisualizer.displayMovementTrails = true

```

2) *Circle Mobility*: The motion in a circular form around a particular point namely centre is known as circle mobility. The following is the code used for circle mobility by our group:-

```
[Config Wireless03]
#Circle Mobility
description = Configuring node movements
extends = Wireless02

*.hostA*.mobility.typename = "CircleMobility"
.host.mobility.cx = uniform(0m , 500m)
.host.mobility.cy = uniform(0m , 500m)
.host.mobility.r = 150m
*.hostA*.mobility.speed = ${speed = 1 .. 20 step 1}mps        # keeping speed from 1 to 20 m/s given in question
*.hostA*.mobility.initialMovementHeading = 270deg

*.host*.wlan[0].queue.packetCapacity = 10         # queue is 10 so that node can hold next 10 datas coming from other nodes while transmitting one

*.visualizer.mobilityVisualizer.displayVelocities = true
*.visualizer.mobilityVisualizer.displayMovementTrails = true

```

Lastly we Using AODV Routing Protocol because of the changing network topology.

```
71 #------------------------------------------------------------------
72 [Config Wireless4]
73 description = Configuring ad-hoc routing (AODV)
74 extends = Wireless03
75
76 *.configurator.addStaticRoutes = false
77
78 *.host*.typename = "AodvRouter"
79
80 *.hostD.wlan[0].radio.displayCommunicationRange = true
81
82 *.visualizer.dataLinkVisualizer.packetFilter = "AODV*"
83
84
```

Tabular Data for Linear Mobility

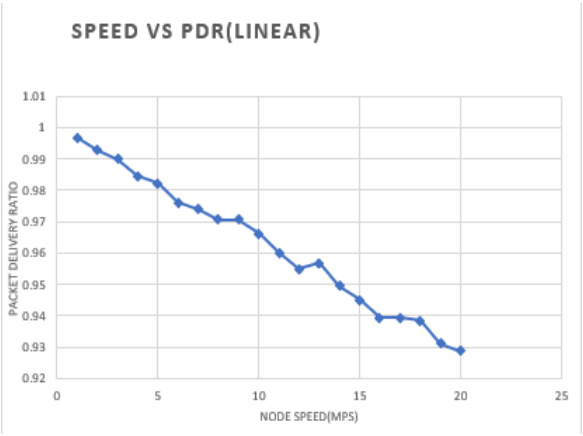
Speed(m/s)	Throughput (mean in bits/sec)	Latency (Seconds)	Packet Delivery Ratio
1	8164.693333	0.000861	0.99666667
2	8132.835556	0.001602	0.99277778
3	8110.08	0.001081	0.99
4	8064.568889	0.001668	0.98444444
5	8046.364444	0.003329	0.98222222
6	7996.302222	0.00192	0.97611111
7	7978.097778	0.002189	0.97388889
8	7950.791111	0.002048	0.97055556
9	7950.791111	0.001595	0.97055556
10	7914.382222	0.002605	0.96611111
11	7864.32	0.004569	0.96
12	7823.36	0.035153	0.955
13	7837.013333	0.003189	0.95666667
14	7777.848889	0.003594	0.94944444
15	7741.44	0.003469	0.945
16	7695.928889	0.004797	0.93944444
17	7695.928889	0.003551	0.93944444
18	7686.826667	0.015771	0.93833333
19	7627.662222	0.060608	0.93111111
20	7609.457778	0.029623	0.92888889

Tabular Data for Circular Mobility

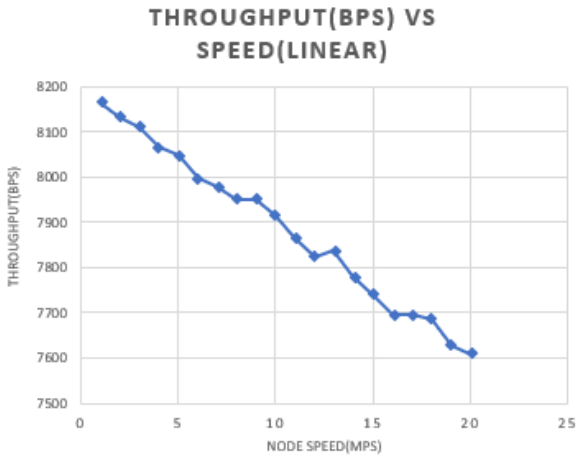
Speed (m/s)	Throughput(mean in bits/sec)	Latency(seconds)	Packet Delivery Ratio
1	8141.93778	0.004992	0.99388889
2	8100.97778	0.006508	0.98888889
3	8069.12	0.007151	0.985
4	8028.16	0.008301	0.98
5	7996.30222	0.010432	0.97611111
6	7968.99556	0.013152	0.97277778
7	7868.87111	0.018056	0.96055556
8	7837.01333	0.018234	0.95666667
9	7814.25778	0.024364	0.95388889
10	7759.64444	0.043563	0.94722222
11	7791.50222	0.023339	0.95111111
12	7700.48	0.030135	0.94
13	7659.52	0.029721	0.93444444
14	7632.21333	0.0302	0.93166667
15	7673.17333	0.028424	0.93666667
16	7545.74222	0.033081	0.92111111
17	7586.70222	0.031095	0.92611111
18	7482.02667	0.053954	0.91333333
19	7472.92444	0.037735	0.91222222
20	7431.96444	0.044501	0.90722222

Graphs For Linear Mobility:

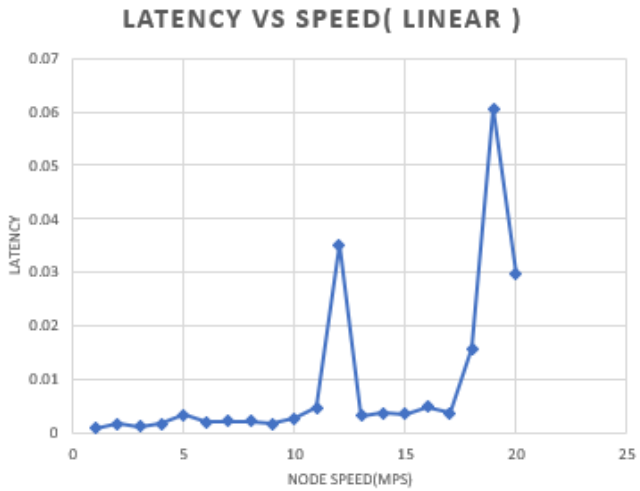
1) Packet Delivery Ratio Vs Nodes Speed:



2) Throughput Vs Nodes Speed:

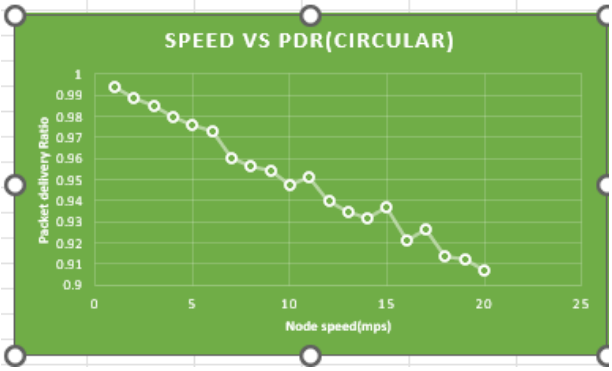


3) Latency Vs Nodes Speed:

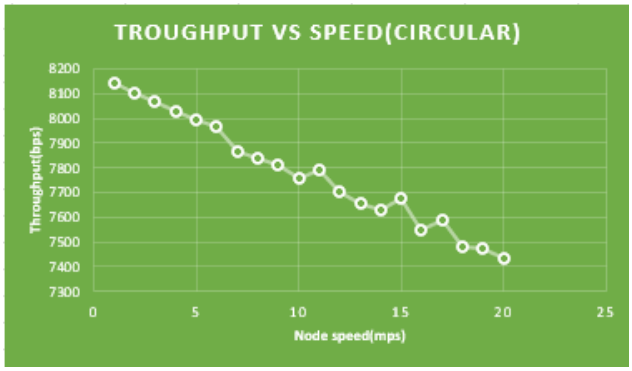


Graphs For Circle Mobility:

1) Packet Delivery Ratio Vs Nodes Speed:



2) Throughput Vs Nodes Speed:



3) Latency Vs Nodes Speed: