TE WHARE WĀNANGA O TE ŪPOKO O TE IKA A MĀUI
VICTORIA
UNIVERSITY OF WELLINGTON

FINAL TEST – 2021

TRIMESTER 1

NWEN 439
SPECIAL TOPIC: PROTOCOLS AND ARCHITECTURES FOR THE INTERNET OF THINGS

Time Allowed: TWO HOURS

CLOSED BOOK

Permitted materials: Only silent non-programmable calculators or silent programmable calculators with their memories cleared are permitted in this examination.

No electronic dictionaries are allowed.

Paper foreign to English language dictionaries are allowed.

ONE A4 sheet, written on ONE side only.

No other material is permitted.

Instructions: Attempt ALL FOUR (4) questions:

1.	IoT Architecture.	[20 marks]
2.	Short-Range Wireless Technologies.	[40 marks]
3.	Long Range Wide Area Networks.	[25 marks]
4.	Routing in Low-Power and Lossy Networks.	[35 marks]

The test consists of 120 marks in total.

1. IoT Architecture **(20 marks)**

   (a) Traditional information technology (IT) systems are primarily concerned with reliable and continuous support of business applications such as databases, web, and electronic mail, among others. Whereas, one key concern in IoT is how to manage massive volumes of data generated by sensors and IoT devices, which can cause network bottlenecks and slow analytics in the cloud. What change is needed to the current network architecture to cope with this challenge? Explain how this change will address network bottlenecks and slow analytics in the cloud. **(6 marks)**

   Sensors generate massive amount of data daily, causing network bottlenecks and slow analytics in the cloud. In traditional IT networks, analytics and applications run only in the cloud. In IoT, analytics capabilities need to be distributed in the network closer to the IoT devices. The distribution of the analytics will aid in balancing the load across the network and moreover, reduce latency as sensors need to transmit their data to nearer analytics components.

   (b) IoT networks are envisaged to support massive scale of IoT endpoints far beyond that of typical IT networks. Explain one limitation of IPv4 that makes it hard to support massive scale deployment and how IPv6 can resolve this issue at the network layer. **(6 marks)**

   One key limitation of IPv4 is the number of addresses it can support. IPv4 address space is already exhausted, necessitating the use of intermediaries such as network address translators which can cause network inefficiencies. Hence, IPv4 will not be able to support the massive scale of IoT devices (without intermediaries). IPv6, which has a vast address space, will be able to support the direct connection of these devices into the Internet.

(c) Explain how latency can be lower when the applications and analytics are deployed closer to the edge. **(8 marks)**

When applications and analytics are deployed centrally in the cloud, the network transmission delay from the IoT devices to the cloud center would be high. In addition, the massive amount of data coming from IoT devices to the cloud would cause core network congestion leading to higher latency. When applications and analytics are deployed closer to the edge (and distributed), congestion would be avoided and at the same time, network transmission time would be much shorter.

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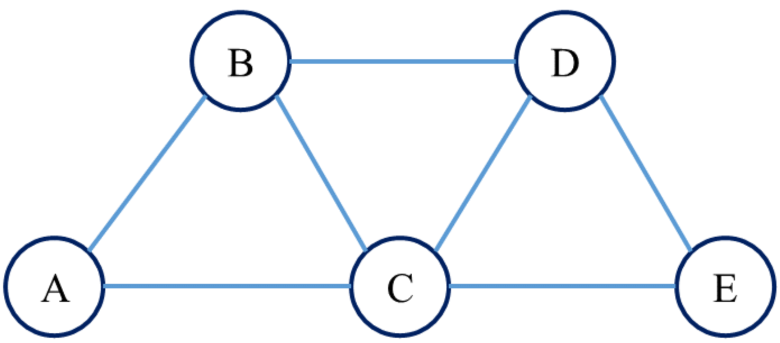
2. Short-Range Wireless Technologies **(40 marks)**

(a) Discuss the motivation behind the development of IEEE 802.15.4. Specifically, talk about two node constraints and how IEEE 802.15.4 addresses those constraints. **(8 marks)**

IEEE 802.15.4 was developed to enable networking of constrained nodes. Constraints include limited memory/storage capacity, limited processing power, and battery-powered operation. IEEE 802.15.4 was developed to be a compact protocol stack capable of transmitting a low rates and short range. Its compactness makes its memory/storage footprint small, and its low data rate and short range makes its power consumption low.

(b) Zigbee uses the routing protocol called Ad hoc On Demand Distance Vector (AODV). A node using AODV does not maintain routes, instead it performs a process known as *route discovery* when it needs to send data to another node and it has no route to that node. Explain how the route discovery process (node A searches a route to node E) would work in the given network. Which path is eventually used from A to E? **(10 marks)**



You can draw diagrams to aid your explanation.

One possibility is:

- A broadcasts a route request (RREQ) packet. B and C receives this RREQ packet.
- B re-broadcasts the RREQ from A. D receives this, and C receives it again. (A receives it but ignores it as it came from itself.)
- C re-broadcasts the RREQ that it directly received from A. E receives this, and E receives this again. (A receives it but ignores it as it came from itself.)
- D re-broadcasts the RREQ it received from B. E receives it again. (B and C receive it but they ignore the packet as they have transmitted it before.)
- E sends back a route reply (RREP) through C. It chooses C because the RREQ from C has lower hop count.
- C forwards the RREP to A.
- A receives the RREP. The route is established from A to E: A-C-E.

(c) In the recent COVID-19 pandemic, Bluetooth Low Energy (BLE) has been considered as a possible technology solution for enabling efficient contact tracing. The key assumption is that a majority of the general population would be carrying mobile devices with BLE interface enabled. The general idea is to use BLE to detect and log "encounters" between individuals. When two individuals come into contact by virtue of them being within close proximity of each other, BLE is used to automatically exchange contact information.

i. You are asked to design a mobile app that uses BLE to log encounters between individuals. For simplicity, define an encounter as a duration in time when the individuals are within BLE range of each other. Using flowcharts, sequence diagrams, or any suitable diagram of your choice, provide a design showing how two user devices will discover each other and exchange contact information. You must clearly show how the user devices will switch between BLE roles to enable discovery and contact information exchange. Provide clear and sufficient explanations about your diagram. You may use either broadcasts or connections, but you will need to justify your choice. Your design must support BLE 4.1 devices (i.e., a device cannot be peripheral and central simultaneously.) **(14 marks)**

(There are many possible designs. The key idea is that a BLE device will have to switch between central and peripheral roles to perform discovery. The dwell times for every role should have some random component, to avoid accidental synchronization which can cause devices not to discover each other.)

ii. Discuss two potential issues (one non-security related and one security related) with your mobile app design that is due to the use of BLE. Explain a possible solution or workaround to each of the identified issues. **(8 marks)**

Possible issues include:

- Long discovery time - causing the device to discover (or not discover) nearby devices for a long time.
- Low number of discovered devices - if discovery process is slow, the number of devices that can be discovered at a given time will be low.
- High power consumption - having the BLE interface always on can cause high power consumption, shortening the battery life of the mobile device.

Possible security issues and solutions:

- Jamming - no solution (if frequency hopping is not able to avoid)
- Sleep deprivation - provide timeout to connections and sleep afterwards
- Privacy - encrypt data exchanged during encounter
- Faulty/fraudulent data - some form of authentication can be performed prior to exchange of data (may require an infrastructure, e.g. an authentication server).

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3. Long Range Wide Area Networks **(25 marks)**

(a) In the legacy IEEE 802.11, a station (STA) operates in two modes: *active* and *power saving* (PS). Briefly describe the operation of a STA in these two modes. **(5 marks)**

active mode – STA is *awake* (ON) and constantly listening for incoming signals; it is able to transmit & receive signals.

power saving mode – STA alternates between *awake* state and *doze* state; in doze state, STA turns off radio components & cannot receive signals;

(b) How does an access point (AP) send data packets to stations in power saving mode? **(5 marks)**

An access point (AP) periodically broadcasts beacon frames containing *Traffic Indication Map* (TIM) *Information Element* (IE), with partial virtual bitmap indicating buffered traffic for STAs in PS mode. If a STA detects buffered packets for it (from the bitmap), it transmits a *PS-poll frame* to AP to request for the buffered packets. It returns to doze state after receiving it.

(c) IEEE 802.11ah defines two classes of power saving STAs: TIM (like legacy 802.11) and non-TIM (*new*).

(i) Compared to TIM STAs, how are non-TIM STAs different?

(ii) Briefly explain how the new *Targeted Wake Time* (TWT) feature of non-TIM STAs work.

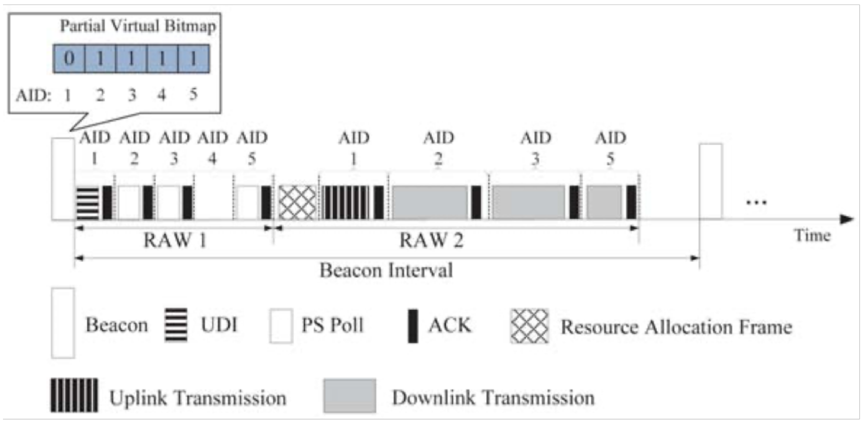
(6 marks)

(i) The non-TIM station class is particularly good for STAs with only uplink data to transmit and no downlink data to receive from the AP, hence buffering info is not included in TIM IE sent by the AP; non-TIM STAs can sleep longer periods without having to wake up periodically to receive beacons;

(ii) The TWT IE is exchanged by *association request* and *association response* frames when an STA associates with (i.e., connects to) an AP, to determine when and how often the STA wakes up for uplink/downlink transmissions. An STA can transmit uplink traffic or request for buffered packets at anytime upon waking up, like the Aloha protocol, in contention with other non-TIM STAs.

(d) For TIM stations, the IEEE 802.11ah standard adds a new concept called *Restricted Access Window* (RAW). With the help of diagram(s), briefly explain how the RAW mechanism works and is able to ensure that selected STAs have contention-free access to the channel. **(9 marks)**

The RAW is a time duration made up of several time slots and AP can indicate to a TIM STA which slot to use for transmitting / receiving packets. An AP includes a *RAW Parameter Set (RPS) IE* in the beacon frame, containing *RAW start time*, *RAW duration*, and *Association IDs* (AIDs) of STAs to which the RAW is allocated.



As shown in the figure, RAW1 is allocated via the beacon & used by STAs to transmit *PS-poll* frames. An STA (e.g. STA with AID 1) uses *Uplink Data Indication* (UDI) field in PS-poll frame to tell AP that it has data to transmit.

Resource Allocation (RA) frame is used by AP to send scheduling info to STAs at beginning of each RAW; all stations assigned to that RAW have to wake up to receive it.

Only STAs granted transmission time slots by the AP can transmit; since AID 4 did not send a PS-poll frame in RAW 1, AP assumes it does not need to transmit and therefore did not allocate any resources to it in RAW 2. Through this procedure, the AP is able to guarantee that the allocated STAs have contention-free access to the channel.

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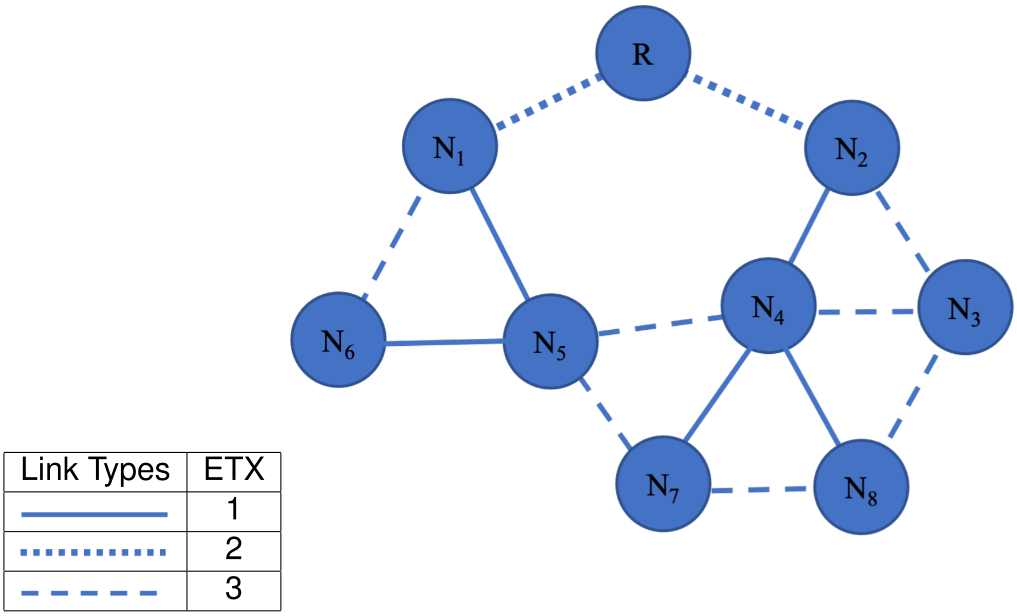
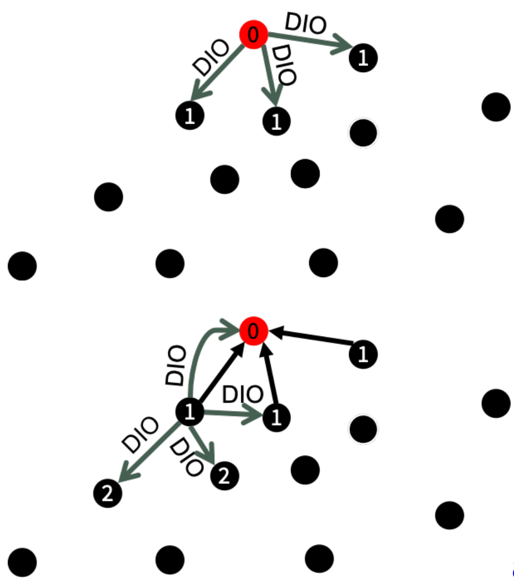
4. Routing in Low-Power and Lossy Networks **(35 marks)**



In the network shown above, node R is the root node. The network is connected by links of different quality (ETX) as shown in the table.

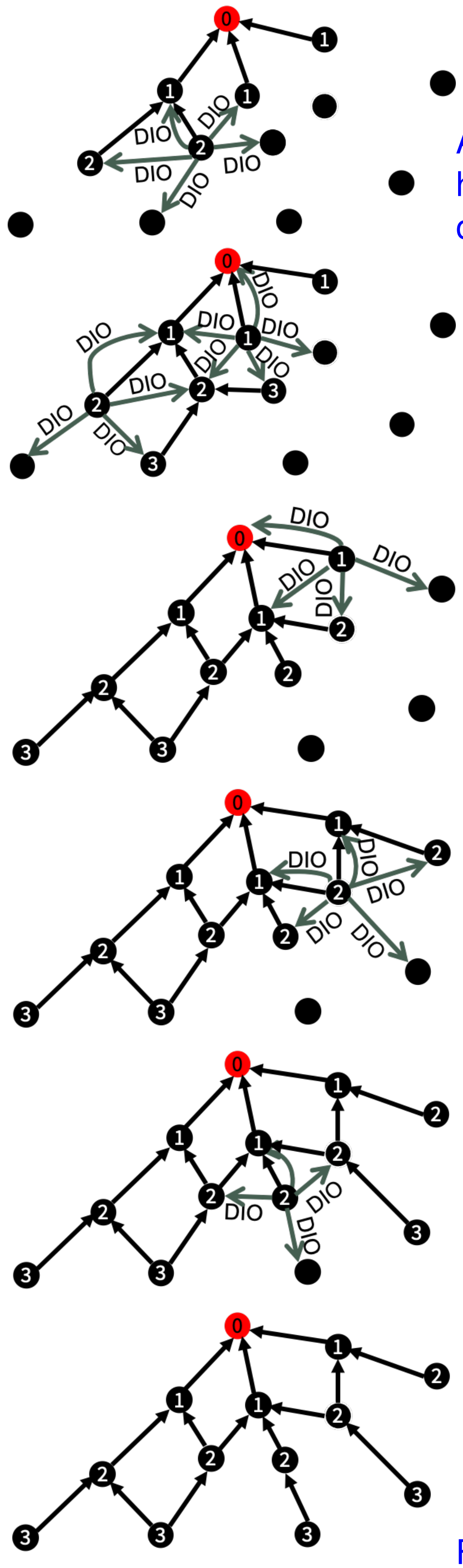
(a) Briefly explain, with the help of diagram(s), how the Destination-Oriented Directed Acyclic Graph (DODAG) is constructed by clearly showing the exchange of DODAG Information objects (DIOs) and how the reverse paths are established in sequence. Assume that each node broadcasts the DIOs in the order of their node numbers, i.e. node R broadcasts first, followed N_1, then N_2, and so forth. **(20 marks)**

Simple explanation together with a set of diagrams similar to the following that were shown in the lecture notes.



Root broadcasts DIOs;

Nodes record parent (root) and (re)broadcast DIOs



A node discards DIOs with higher rank value than its own.

Final DODAG

(b) When N_3 sends a packet to N_7, briefly discuss the advantages and disadvantages of using the storing mode vs non-storing mode for downward routing in terms of (i) memory requirements, (ii) control overheads, and (iii) latency. **(15 marks)**

Non-storing mode Every node sends Destination Advertisement Option (DAO) message containing its parents list to the root, R; R computes paths to all possible destinations in its DODAG and stores in its routing table; messages are then sent using *source routing*;

(i) memory requirements are high on root but low on all other nodes, since only root stores routing table;

(ii) control overheads are higher as DAO messages have to go all the way to the root, and packets need to contain the entire route from root to destination;

(iii) N_3 needs to send packet all the way to root, which then sends it down to N_7, so higher latency.

Storing mode Each node sends DAO messages to its parents only; each non-root/non-leaf node maintains a routing table for all possible downstream destinations;

(i) every non-root/non-leaf node needs to store a routing table, so memory requirements are higher on all these nodes as compared to non-storing mode;

(ii) control overheads are lower as DAO messages only need to be sent to parents; packets also don't need to contain full source route;

(iii) lower latency as N_3 only needs to send packet up to nearest common parent, N_2, which then sends it down to N_7.

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