COMP 32412

Two hours

UNIVERSITY OF MANCHESTER
SCHOOL OF COMPUTER SCIENCE

The Internet of Things: Architectures and Applications

Date: Friday 24th May 2019

Time: 09:45 - 11:45

Please answer all THREE Questions
Each question is worth 20 marks

Use a SEPARATE answerbook for each SECTION

This is a CLOSED book examination

The use of electronic calculators is permitted provided they are not programmable and do not store text

[PTO]

Section A

COMPULSORY

Please answer both questions

1. Answer **ALL** parts of this question (20 marks).

   a) In an IoT system for smart irrigation, we monitor the level of soil moisture in a greenhouse and the water supply is regulated through a valve that can be controlled remotely. We aim to develop a reference model for this system. As part of this development process:

      i. Specify how many virtual entities (VEs) are required for the Domain model. Which physical entities do these VEs represent? (3 marks)

      ii. Using the provided general template of the information model in Figure 1, produce the information model for each VE you listed in part (i), including the appropriate cardinalities in each model. (7 marks)

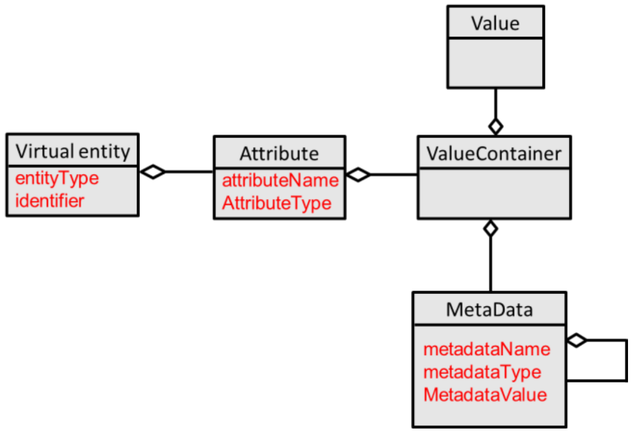

Figure 1. Information Model for a virtual entity (without cardinalities).

   b) A developer of IoT systems has produced part of the domain model for a smart factory system as shown in Figure 2.

      i. Explain briefly whether there any errors in the associations shown in Figure 2 and, if yes, provide an appropriately corrected drawing. (2 marks)

      ii. In addition, determine the category (e.g., software, hardware, etc.) for each of the illustrated classes. (1 mark)

      iii. In this IoT system, high speed communication is required between the Devices and the Cloud resources. Which web communication technology should be used to satisfy this requirement and why? (2 marks)

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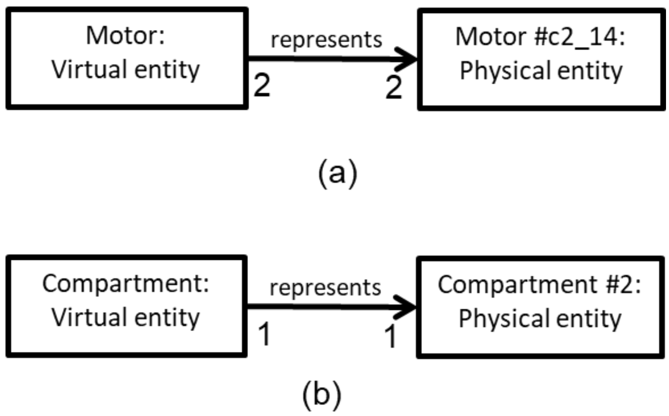

Figure 2. Part of the domain model for an IoT smart factory.

c) How is binary information encoded with the binary Frequency Shift Keying? Provide a short description and offer a schematic illustration of the transmission of the half byte “1101” (endianness is irrelevant in this question).

(3 marks)

d) Assume the common scenario where two wireless networks are present indoors. These networks are the standard WLAN based on IEEE.802.11 and classic Bluetooth. Briefly explain which of these two networks behaves as the primary interferer and why. (2 marks)

2. Answer **ALL** parts of this question (20 marks).

a) We want to construct a Scatternet consisting of 22 devices utilizing the Bluetooth standard protocol.

i. How many piconets are minimally required in order to produce such a Scatternet? (you can either provide a textual answer or draw a diagram that reflects the required Scatternet). (2 marks)

ii. If synchronization issues within this Scatternet are ignored, what is the **minimum** and **maximum** number of hops required to support communication between any two nodes in this Scatternet? Explain your answer either textually or schematically, but explicitly state the number of hops. (5 marks)

iii. Assume that the distance between any two nodes within the same piconet does not exceed 50 metres. In addition, the sensitivity of the receiver in each node is -40 dBm. Assuming that the path loss follows the average log-distance model, determine whether a power class-II (2.5 mW) transmitter is appropriate for this receiver. The propagation path is assumed to be characterized through a log-distance path loss model (in dBm) described by:

$$P_{Rx} = P_{Tx} + K - 10nlog\left(\frac{d}{d_0}\right),$$

where K = 3 dBm and the path loss exponent is 3. The reference distance is 0.5 m. (3 marks)

b) In a communication system, we desire to support full duplex communication between users. However the given bandwidth is heavily constrained and frequency division is not an option. How can we enable full duplex communication is this scenario? (2 marks)

c) A wireless AP based on IEEE 802.11b has an indoor range of 25 m with a communication bit rate of 11 Mbps. We desire to extend this range to 50 m. Describe potential ways to achieve that and, if applicable, the related tradeoffs. (3 marks)

d) Suppose we want to build a wireless LAN (WLAN) with a small number of devices, where we want to have low latency between data transfers.

i. Which of the two primary communication methods for WLANs is preferable in this scenario and why? (3 marks)

ii. Within the context of IoT systems what is the limitation that may result from the choice of this method for the developed wireless LAN? (2 marks)

Section B

COMPULSORY

3. Answer **ALL** parts of this question (20 marks).

A house has a thermostat which keeps the internal temperature in the range

$$[T_{int}, T_{int} + \Theta] = [19^oC, 20^oC]. \tag{1}$$

When the heating system is switched off, the temperature T in the house declines in time t following Newton's law of cooling:

$$\frac{dT}{dt} = -\gamma_c(T - T_{ext}), \qquad T(0) = T_0, \tag{2}$$

where T_0 is the internal temperature at time $t = 0$ and T_{ext} is the external temperature. The analytical solution of (2) is given by

$$T(t) = T_{ext} + (T_0 - T_{ext})e^{-\gamma_c t}. \tag{3}$$

a) Assume that T_0 = 20^{o}C, T_{ext} = 12^{o}C and γ_c = 0.01 $\left[\frac{1}{min}\right]$. Compute the time t_1^{exp} required for a home to cool down to T_{int} = 19^{o}C using formula (3). (5 marks)

b) Compute the home cooling time t_2^{exp} if the external temperature falls to $T_{ext} = 3^o$C. (2 marks)

c) The exponential solution model (3) can be approximated by a linear model under the assumption $T - T_{int} \ll T_{int} - T_{ext}$. The linear model is obtained from (3) by replacing the exponential term with a linear Taylor expansion (hint: we just keep the two first terms in the Taylor expansion, i.e. $e^{-x} \approx 1-x$). Apply the linearised formula obtained in this way to determine the time t_i^{lin}, i = 1,2, required for a home to cool down from T_0 = 20^{o}C to T_{int} = 19^{o}C when 1) $T_{ext,1} = 12^oC$, 2) $T_{ext,2} = 3^oC$. Compute the relative errors in both cases

$$e_i = \frac{\left|t_i^{lin} - t_i^{exp}\right|}{t_i^{exp}}, \; i = 1,2, \tag{7}$$

where t_i^{lin} are the cooling times obtained by the linearised model and t_i^{exp} are the cooling times obtained from Part a) with $T_{ext,i}, i = 1,2$, respectively. Explain the obtained relative error results. (7 marks)

d) Consider the case when the thermostat switches on periodically when the internal temperature in a house falls to T_{int} = 19^{o}C and switches off when the temperature reaches $T_{int} + \Theta$ = 22^{o}C (see Figure 3). The heating and cooling parameters are τ_h = 2^{o}C/hour and τ_c = 1^{o}C/hour. The electricity tariffs over the 6 hour period of interest are given in the Table 1.

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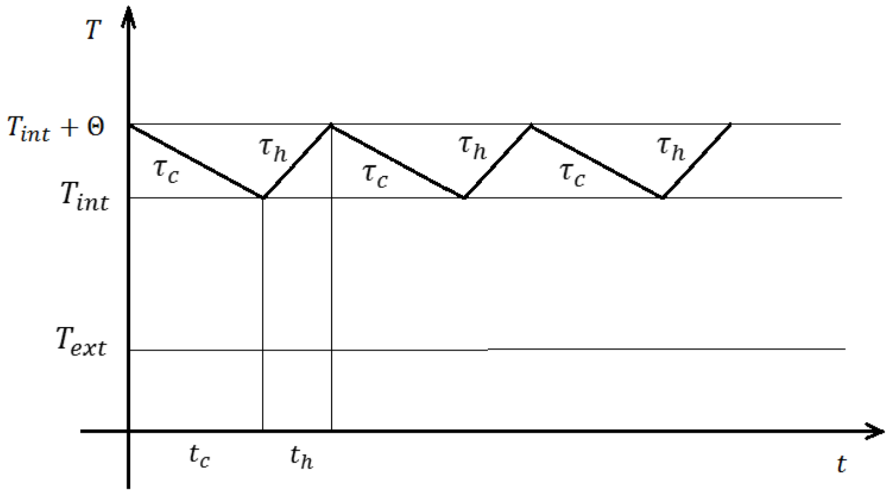

Figure 3: Temperature profile.

Table 1. Electricity tariffs over time.

Time (hours)	0-2	2-4	4-6
Price (pence/unit)	5	7	15

Assume that at $t = 0$ the interior temperature is $T_{int} + \Theta$ and that the thermostat switches off. Compute the cost of heating the home over the 6 hour period if heating the home for 1 hour uses 10 units of electricity. Suggest a switching strategy which would reduce the cost of heating over the 6 hour period under consideration. In your answer you can assume that the thermostat can be switched on/off remotely at any time and that the initial temperature at t = 0 can have any value between T_{int} and $T_{int} + \Theta$. Justify your answer. (6 marks)

END OF EXAMINATION