Waste Disposal Infrastructure

Wireless, Sensor and Actuator Networks

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ABSTRACT

90% of the world's waste is collected at the wrong time. When it's picked-up too late, overflowing containers lead to waste in nature. When waste is collected too early, empty waste bins waste time and collection resources. Optimizing the waste collection time, can increase waste collection rates and reduce litter, while also reducing collection costs [1]. IoT and smart sensors we can provide a more efficient way to collecting waste.

We've been asked our local council who are interested in developing a smart city infrastructure to increase the quality of services provided to their residents and to optimise operational costs. They're looking at applications for smart bins and this paper will provide a report outlining the reference architecture of the system focusing on the IoT aspect and the backhaul communication networks.

These smart bins should be fitted with connected sensors that will allow the bins to relay information to their local data centre for this operation. The information should be able to tell the council whether garbage needs to be collected and specialized algorithms will compute the optimal routes for collection tracks daily.

Implementing this section of IoT and circular economy has made some amazing strides with San Francisco having an 80% decrease in overflowing trash cans, 66% decrease in street cleaning service requests and illegal dumping. [2]

KEYWORDS

Ultrasonic, Sensors, IoT, Circular Economy, Optical Laser, 4G, Wi-Fi, Network, Topology, Energy Balance Protocol

1 Sensing Modalities

When deciding which sensor technology, the local council should use we first have to take into consideration multiple factors. Ultrasonic sensors are smart sensors that measure the distance of a target by emitting ultrasonic sound waves and converting the returning echo into an electrical signal. This type of sensor is a potential choice in picking which sensors to use in this circular economy, however standard ones are quite large and bulky, they require multiple sensors to provide accurate readings due to the nature of struggling with different distances, shapes and sizes meaning the council would have to allocate additional funds for more sensors. It should also be noted that ultrasonic sensors have what's called a "warm-up drift" meaning the sensors can't guarantee accurate measurements until they're operating at correct temperatures which must also be considered if they're suspectable to cold temperatures [3]. In addition to this, they're quite power hungry to be providing 24/7 readings so instead we would have readings sent to the local data centre in intervals. We also must consider if the sensor will get blocked and or removed from the actual bin. [2]

Another option for a smart sensor is optical laser which would be much more efficient to use than ultrasonic sensors and is more recommended for smart waste management projects. They're much more accurate, able to measure and gather data from uneven surfaces and allows the data centre to produce 3D topology maps of the respective smart bin. They're also more efficient in context of power and are smaller and more discreet [3].

There are also external factors that we should consider first not directly related to the sensors themselves. We need to consider the location of the smart bins and whether the smart sensors that are implemented offer 4G as a connective option and the area where this project is supports 4G. We should also consider the type of waste container that will be used as not all bins are suitable for smart sensors. Below you can see some typical bins that are suitable [3].

Figure 1: Suitable waste containers from Nord Sense.

2 Network Technologies

When creating what this network will look like and the technology used it's important to look research and choose the best topology for our scenario. Figure 2 shows potentially what our network could look like written down on paper. We provide a network that engulfs a range of sensor nodes which would be our smart bins. This is all connected to a central base station inside the council main building which will then connect to the internet and then connecting to tablets that will be installed in the garbage trucks. It's important to also notice that a satellite and a Wi-Fi tower is also connecting to the node to portrait 4G.

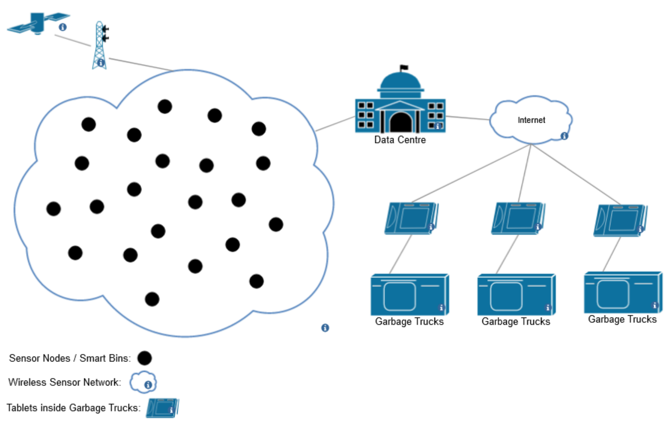

Figure 2: Wireless Sensor Network Diagram [5].

The sensor nodes acting as our bins will use optical lasers and keep a reminder of when a bin gets filled. This data is then transmitted to our data centre where the specialized algorithm will compute the optimal routes for collection and then send this information along to network connected tablets where the workmen will be able to follow.

The placing of the nodes will be deterministic based on several factors including distance between each node, distance between the node and the data centre and finally the conditions to the environment such as whether the sensors will ensure harsh environments or hostile operations.

For example, if we were to have a network with N = 20, the distance between each sensor is d = 5m, distance between node Z and the data centre = DC is D = 10m, $d_r = 1$, $d_f = 0.9$, each message is 10 bits, $E_c = 50[nJ/bit]$ and $E_{tx}(d) = kd^2, where\ k = 1$. Node Z and DC has a $d_f = 0.5$.

ETX = $d_{A-Z} = 20\left(\frac{1}{0.9}\right) \simeq 22.22,\ d_{Z-DC} = 1\left(\frac{1}{05}\right) \simeq 2$

Energy Consumption = $Path\ d_{A-Z} = 22.22\ x\ (E_c\ x\ b + E_{tx}(5)\ x\ b + E_c\ x\ ) = 22.22\ x\ (50\ x\ 10 + 1\ x\ 5^2\ x\ 10 + 50\ x\ 10) = 27{,}772[nJ] = 27.78[\mu J]$

$$Path\ d_{Z-DC} = 2\ x\ (E_c\ x\ b + E_{tx}(10)\ x\ b + E_c\ x\ )$$
$$= 2\ x\ (50\ x\ 10 + 1\ x\ 10^2\ x\ 10 + 50\ x\ 10)$$
$$= 4000[nJ] = 4[\mu J]$$

$$Path\ d_{A-DC} = 27.78[\mu J] + 4[\mu J] = 31.78[\mu J]$$

To extend the network will be easy, all that is needed is to connect the additional sensors to the network where they will work with each other and the other components of this network. We can also consider if the network density begins to grow exponentially, we can introduce a different network topology where each area of nodes will have a cluster head that connects to the data centre. If another topology had to be chosen, we also must consider how each of the nodes relate to each other such as single hop or multi hop as different methods consume different amounts of power [4]. We will be considering using Energy Balance Protocol (EBP) as this guaranties that each sensor will be using the same amount of energy, taking into considering that each sensor will be the same distance from each other all around the city means that EBP would be the perfect protocol to use. Each smart sensor and tablet device will have an interface password protected with a complex policy to ensure security and integrity.

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Questions

Global Assumptions

These assumptions have been made for multiple questions:

- The energy required to operate the radio module for each bit (both receiving and transmitting) is $E_c = 50[nJ/bit]$;
- The energy required to successfully transmit a message over distance is d is $E_{tx}(d) = kd^2, where\ k = 1$;
- When determining the E_{tx} metric, $d_r = 1$;

Question 1

Question 1A

Energy Balance Protocol (EBP) is a protocol implemented into a wireless sensor network to prolong the life of a network by ensuring that each sensor on the network consumes the same amount of energy. This is done by first partitioning the network into a range of sectors called "slices" over the transmission range. Each message is propagated so that the average per sensor energy dissipation is the same for all sensors. This protocol differs from Local Target Protocol (LTP) which is considered greedy and is a single-path optimisation where each message is from node to node.

Question 1B

Consider a wireless sensor network consisting of wireless sensor motes. Assume that the network uses the LEACH routing protocol configured to operate in eras of 8 rounds each, with 12% of the motes acting as cluster-heads in each round. Describe and show how the cluster-head election algorithm would

- *N: Number of sensor nodes. N=350;*
- *P: The desired percentage of cluster heads. P = 12%;*
- *R: The current round;*
- *G: Set of nodes that have not been cluster-heads in the last $\frac{1}{P}$ rounds*

$$\mathrm{r} = 0; \mathrm{G} = 350 \rightarrow \mathrm{T}(n) = \left(\frac{0.12}{0 - 0.12(0\ mod\ \left(\frac{1}{0.12}\right)}\right)$$
$$= 0.12\ x\ 350 = 42CHs$$

$$\mathrm{r} = 1; \mathrm{G} = 308 \rightarrow \mathrm{T}(n) = \left(\frac{0.12}{1 - 0.12(1\ mod\ \left(\frac{1}{0.12}\right)}\right)$$
$$= 0.13636363636\ \ x\ 308 = 42CHs$$

$$\mathrm{r} = 2; \mathrm{G} = 266 \rightarrow \mathrm{T}(n) = \left(\frac{0.12}{1 - 0.12(2\ mod\ \left(\frac{1}{0.12}\right)}\right)$$
$$= 0.15789473684\ x\ 266 = 42CHs$$

$$\mathrm{r} = 3; \mathrm{G} = 224 \rightarrow \mathrm{T}(n) = \left(\frac{0.12}{1 - 0.12(3\ mod\ \left(\frac{1}{0.12}\right)}\right)$$
$$= 0.1875\ x\ 224 = 42CHs$$

$$\mathrm{r} = 4; \mathrm{G} = 182 \rightarrow \mathrm{T}(n) = \left(\frac{0.12}{1 - 0.12(4\ mod\ \left(\frac{1}{0.12}\right)}\right)$$
$$= 0.23076923076\ x\ 182 = 42CHs$$

$$\mathrm{r} = 5; \mathrm{G} = 140 \rightarrow \mathrm{T}(n) = \left(\frac{0.12}{1 - 0.12(5\ mod\ \left(\frac{1}{0.12}\right)}\right)$$
$$= 0.3x\ 140 = 42CHs$$

$$\mathrm{r} = 6; \mathrm{G} = 98 \rightarrow \mathrm{T}(n) = \left(\frac{0.12}{1 - 0.12(6\ mod\ \left(\frac{1}{0.12}\right)}\right)$$
$$= 0.42857142857\ x\ 98 = 42CHs$$

$$\mathrm{r} = 7; \mathrm{G} = 56 \rightarrow \mathrm{T}(n) = \left(\frac{0.12}{1 - 0.12(7\ mod\ \left(\frac{1}{0.12}\right)}\right)$$
$$= 0.75\ x\ 56 = 42CHs$$

Question 3

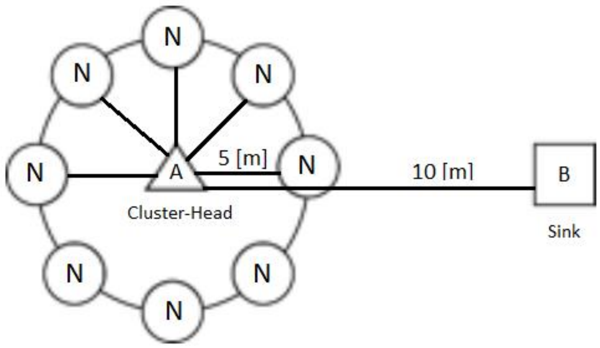

Figure 3: PAN network from question 3.

- The sensors (circles) periodically report their temperature measurements to the cluster-head of the PAN (triangle), which then relays each measurement to the Sink (square); the Sink computes the average.
- The sensors periodically report their temperature measurements to the cluster-head. The cluster head aggregates the received data by computing the average value, which is then transmitted to the Sink.

Calculate the total network energy consumption to get one averaged temperature value at the Sink for ($N = 4$) sensor nodes. Based on your intuition, is there a case where it would be more energy efficient to perform the averaging operation at the Sink and which one? Explain and present your arguments in a formal (mathematical) way. Each message containing a temperature reading is 127[$Bytes$] or 1016[$bits$] long.

Question 3, Scenario 1

$$\begin{aligned} Path\ d_{N-A} &= (E_c\ x\ b + \ E_{tx}(5)\ x\ b + E_c\ x\ \ b)\ x\ N \\ &= (50\ x\ 1016 + 1\ x\ 5^2\ x\ 1016 \\ &\quad + 50\ x\ 1016)\ x\ 4 = 617{,}728[nJ] \\ &= 617.73[\mu J] \end{aligned}$$

$$\begin{aligned} Path\ d_{A-B} &= (E_c\ x\ b + \ E_{tx}(10)\ x\ b + E_c\ x\ \ b)\ x\ N \\ &= (50\ x\ 1016 + 1\ x\ 10^2\ x\ 1016 \\ &\quad + 50\ x\ 1016)\ x\ 4 = 820{,}928[nJ] \\ &= 820.93[\mu J] \end{aligned}$$

$$Path\ d_{N-A-B} = 820.93[\mu J] + 617.73[\mu J] = 1438.66[\mu J]$$

Question 3, Scenario 2

$$\begin{aligned} Path\ d_{N-A} &= (E_c\ x\ b + \ E_{tx}(5)\ x\ b + E_c\ x\ \ b)\ x\ N \\ &= (50\ x\ 1016 + 1\ x\ 5^2\ x\ 1016 \\ &\quad + 50\ x\ 1016)\ x\ 4 = 617{,}728[nJ] \\ &= 617.73[\mu J] \end{aligned}$$

$$\begin{aligned} Path\ d_{A-B} &= (E_c\ x\ b + \ E_{tx}(10)\ x\ b + E_c\ x\ \ b) \\ &= (50\ x\ 1016 + 1\ x\ 10^2\ x\ 1016 \\ &\quad + 50\ x\ 1016) = 205{,}232[nJ] = 205.23[\mu J] \end{aligned}$$

$$Path\ d_{N-A-B} = 205.23[\mu J] + 617.73[\mu J] = 822.96[\mu J]$$

From my calculations, as it stands the energy consumed to send all 4 messages from the nodes to the cluster-head then to the sink would consume 1439[μJ] whereas if the averaging operation was performed at the cluster-head it would mean that only a single message of 1016[bits] would have to be sent from the cluster-head to the sink consuming only 823[μJ].

Question 5

Figure 4: Network Topology from Question 5.

Calculate the expected overall network energy consumption for routing one packet of length $b = 100[bits]$ from A to C via multi-hop transmission. The expected overall network energy consumption is 72.5[μJ].

$$\begin{aligned} Path\ d_{A-B} &= 4.3\ x\ (E_c\ x\ b + \ E_{tx}(5)\ x\ b + E_c\ x\ \ b) \\ &= 4.3\ x\ (50\ x\ 100 + 1\ x\ 5^2\ x\ 100 \\ &\quad + 50\ x\ 100) = 53{,}750[nJ] \end{aligned}$$

$$\begin{aligned} Path\ d_{B-C} &= 1.5\ x\ (E_c\ x\ b + \ E_{tx}(5)\ x\ b + E_c\ x\ \ b) \\ &= 1.5\ x\ (50\ x\ 100 + 1\ x\ 5^2\ x\ 100 \\ &\quad + 50\ x\ 100) = 18{,}750[nJ] \end{aligned}$$

$$\begin{aligned} Path\ d_{A-B-C} &= 53{,}750[nJ] + 18{,}750[nJ] = 72{,}500[nJ] \\ &= 72.5[\mu J] \end{aligned}$$

Question 6

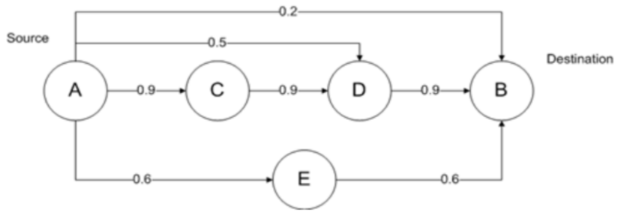

Figure 5: Network Topology from Question 6.

Calculate the optimal E_{tx} route from source A to destination B. The optimal E_{tx} route from Source A to destination B is $Path\ d_{A-D}$ which requires 3.11 re-transmissions.

$$Path\ d_{A-B} = 1\left(\frac{1}{0.2}\right) \simeq 5$$

$$Path\ d_{A-D} = 1\left(\frac{1}{0.5}\right) \simeq 2 + \left(d_{D-B} = 1\left(\frac{1}{0.9}\right)\right) \simeq 1.11 \ \simeq 3.11$$

$$Path\ d_{A-C-D-B} = 3\left(\frac{1}{0.9}\right) \simeq 3.33$$

$$Path\ d_{A-E-B} = 2\left(\frac{1}{0.6}\right) \simeq 3.33$$