Study of Energy-Saving MAC Routing protocols in Wireless Sensor Networks (WSN).

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***Abstract*— In this report, energy-efficient MAC routing protocols are discussed. Simulations are performed to better understand how S-MAC, T-MAC and ZigBeeMAC impact energy consumption. This is then analyzed and discussed in terms of sample rate and node density with further investigation into possible reasons for higher or lower energy consumption. Comparisons between different radio specifications, CC1000 and CC2420 and how they affect the energy consumption when using the different protocols are also made. Results showed that while T-MAC performed better in the later iterations of tests the protocol that consumed the least energy in the simulated network was S-MAC. All three protocols showed potential applications depending on the requirements of a network.**

Keywords*— *S-MAC; T-MAC; ZigBeeMAC; Energy-efficiency; Minimise;

Word Count - 1998

I. INTRODUCTION

Wireless Sensor Networks (WSN) consist of multiple sensor nodes dispersed over an area. They are deployed in an attempt to monitor and record the physical conditions and characteristics of the area. WSNs are used in a multitude of different applications, with different deployments varying in size and complexity. WSNs forward data between nodes until it either reaches a network gateway or central node (Base Station (BS)). Sensors in a WSN can be difficult to access once deployed and must operate using a limited power supply. Sensors and by extension the mesh network they are implemented within must therefore be designed to maximise energy efficiency to reduce the need for replacement and increase the lifespan of the network. This report discusses the impact that different energy-efficient MAC addressing protocols have on the energy consumption of a WSN. This is discussed in terms of sample rate and node density. The protocols tested include:

- S-MAC: Sensor-MAC (SMAC) is an addressing protocol that utilises scheduled sleep cycles to switch sensors between sleep and listening modes to conserve energy. Schedules are maintained with neighbouring nodes where they form local “clusters”. There can be multiple clusters in a WSN (Khatarkar & Kamble, 2013)
- T-MAC: Timeout-MAC (TMAC) is a protocol derived from S-MAC where nodes will also periodically enter sleep and active modes to conserve energy. However, when in the active mode the node finishes its transmission before sleep. The node will also automatically enter the sleep mode if no activity is recorded after a minimum listening period. (Khatarkar & Kamble, 2013)
- ZigBeeMAC: ZigBeeMAC utilizes 3 components coordinator, router, and end device. The coordinator stores and receives information, routers forward information and end devices utilise or create information. In a WSN sensors can act as both routers and end devices to create a mesh network. Efficiency and low transmission rates are key to conserving energy. (Amin & Saeed, 2018)

The report will aim to find the protocol that consumes the least energy in a simulated WSN.

II. SETUP AND ANALYSIS

A. *Simulation Tools*

This investigation uses Castalia, an OMNeT++ based platform that uses the Log-distance path loss model (lognormal shadowing model) (Zuniga & Krishnamachari, 2004). This means it can model the average path loss in Wireless Sensor Networks (WSN), Body Area Networks (BAN) and other low-power wireless networks. The Castalia bridge test is used.

B. *Background*

The simulation scenario consists of a car and a bridge. The bridge has an area of 100m x 40m and is 10m off the ground. The car moves between coordinates (0,10) and (100,10), this simulates the car moving across the bridge. This is done every 5 minutes causing nodes to transmit data. A “patch” causes the traffic received to reverse and flow from sink to node at the start of each “day”.

C. *Network*

18 wireless sensor nodes and a single sink node were used. The nodes were uniformly distributed across the area of the bridge in 6 rows of 3. The network utilised S-MAC, T-MAC and ZigBeeMAC in 4 different tests. The first two tests would show energy consumption vs varying sample rates (10, 20, 30, 40, 50) the first test using the radio model CC1000 and the second using CC2420. The final two tests would show the energy consumption vs node density (10, 20, 30, 40, 50, 60)

and again each test would use the different radio models. The network does not use Ip routing.

Table 1

Parameters	Values
Simulation Time	300s
Application	Bridge Test
The Sink Node (0)	True
Number of Nodes	19
Field size	100m x 40m
Battery	18,720 J (2x AA Batteries)
Radio Transmitter power	-10dBm
Radio type	CC2420 and CC1000
MAC Algorithm	ZigBeeMAC, TMAC and SMAC
Vary Sample Rate	10, 20, 30, 40, 50
Vary Node Density	10, 20, 30, 40, 50, 60
Data rate	1024 Kbps
Sample Rate (Test 3,4)	100ms
Initial Power consumption	Two AA batteries
Routing Protocol	Bypass routing

III. RELATED WORKS

Wireless sensor networks are often deployed in scenarios where a reliable power supply would be impossible to guarantee. Applications that fall under this category include military, medical, and industrial applications where access to nodes may be difficult or impossible (Chai, Wang, Zhang, Cui, & Chai, 2020). The harsh operating conditions require sensors to be energy efficient to improve the longevity of individual nodes also allowing nodes to act individually as well as being part of a network. As discussed within this report, Sensor-MAC, Timed-MAC and Zigbee protocols can be used within a WSN to minimise the overall energy consumption. Other energy-efficient protocols include:

- DEE-MAC: DEE-MAC reduces energy consumption by letting idle listening nodes go into sleep. This is done using cycle synchronization performed by a cluster head. DEE-MAC creates clusters at the beginning of an "event" with the cluster head being elected based on the remaining power (Rezaei & Mobininejad, 2013).
- SPARE-MAC: SPARE-MAC attempts to save energy by limiting the impact of idle listening and overhearing. SPARE-MAC utilises a distributed scheduling system which assigns specific radio resources to each sensor node, this is called Reception Schedules (Rezaei & Mobininejad, 2013).
- WiseMAC: WiseMAC utilises a preamble sampling technique to decrease idle listening time. When transmitting a frame, nodes prepend preambles of variable length to alert receivers to signal that they should stay awake for the upcoming frame transmission (Hurni, Braun, & Anwander, 2010).

WSNs typically utilise multi-hop architectures to reduce transmission distance and improve energy efficiency. WSNs traditionally use one of two multi-hop network architecture types - flat and hierarchical (cluster) (Moschitta & Neri, 2013). Flat architecture requires each node to play the same role in sensing and transmitting information (Khatarkar & Kamble, 2013). Cluster architecture is where one or more nodes are designated as a head node responsible for communication with other clusters or directly to the sink node (Moschitta & Neri, 2013). Protocols that utilise cluster architecture include but are not limited to DEE-MAC, S-MAC, and T-MAC. Both architectures aim to reduce the number of nodes a frame must be passed through thus reducing resource use and energy consumption.

Future applications of WSNs could include marine deployments for environmental study and protection. A WSN deployed in ocean territories in theory could provide better detection and earlier warning for natural disasters such as tsunamis (M. Ammari, et al., 2016). Smart homes are homes with several integrated systems to make the home "aware" of activities within the household (M. Ammari, et al., 2016) this is similar to a Hive a "smart" thermostat but with more features such as security monitoring and behaviour tracking.

IV. RESULTS

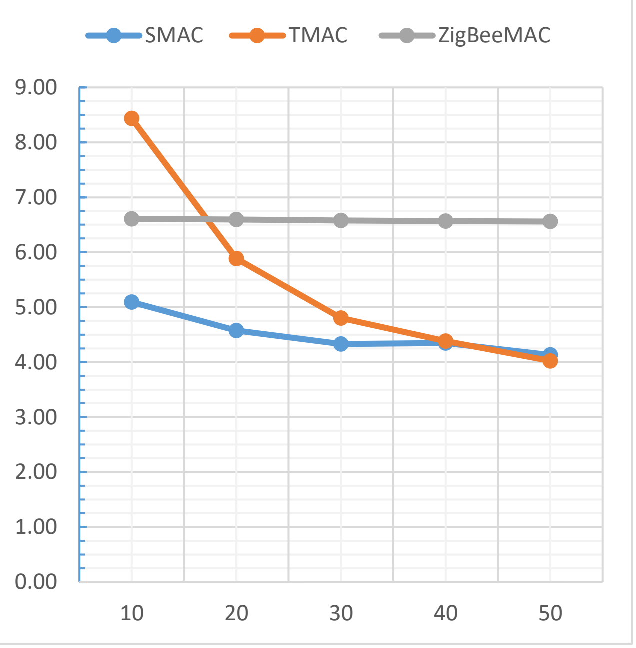

Figure 1 - Energy Consumption Vs Sample Rate - CC1000

Test 1 (Table 2) looked at the total energy consumption of each protocol vs sample rates between 10 and 50 (in increments of 10) using the CC1000 radio specification. The

above graph shows that increasing the sample rate reduced the energy consumption of each protocol. This is expected as although a higher sample rate means increased energy needed to produce a signal if the receiving device can process it fast enough the time needed for transmission can be reduced. This reduces active time saving energy.
S-MAC showed the lowest overall energy consumption between sample rates 10 and 40. At sample rate 50 it still showed the second lowest energy consumption at 4.13 (3 sf). This meant that S-MAC had the lowest average energy consumption at 4.50 (3sf). S-MAC was very consistent overall and had the second least variation between intervals. Both S-MAC and T-MAC extend the work of PAMAS and propose overhearing avoidance (Chang, Huang, & Lin, 2013). This attempts to reduce energy consumption through the minimisation of unnecessary listening (overhearing) from devices this is similar to the technique of adaptive sleeping (Ye, Heidemann, & Estrin, 2004). This is done by sending the device into a sleep state when it receives a request to send (RTS) or clear to send (CTS) (Chang, Huang, & Lin, 2013). The results above can be partially attributed to this feature as both protocols enabled with this feature show lower energy consumption.

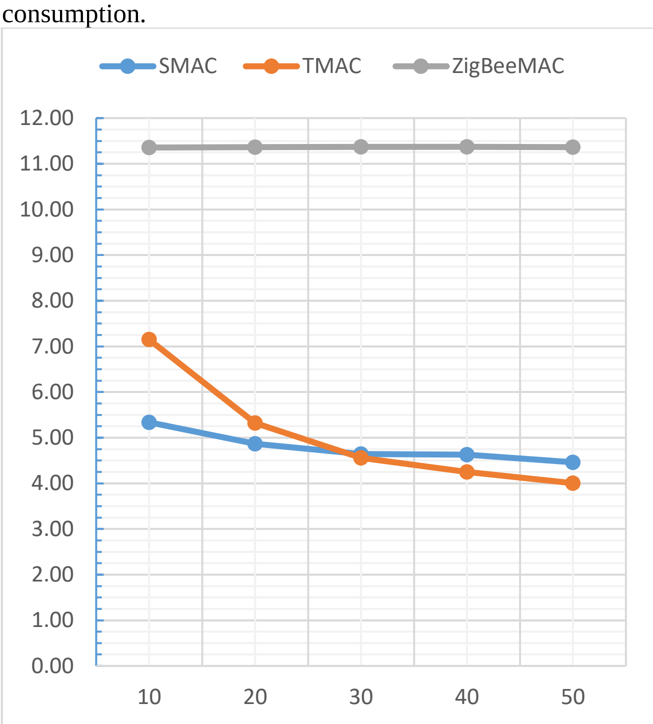

Figure 2 - Energy Consumption Vs Sample Rate - CC2420

Test 2 (Table 3) looked at the energy consumption vs sample rate again between 10 and 50 at intervals of 10 but using radio specification CC2420. The above graph shows higher energy consumption using CC2420 vs CC1000. This could be due to the frequency ranges each specification operates at. With CC1000 operating between 300 and 1000 MHz and CC2420 operating at a minimum of 2400MHz. In Planck-Einstein's relation, a higher frequency wave on the electromagnetic spectrum has more energy (Ward, 2016). This means the higher operating frequency of CC2420 would cause more energy to be consumed regardless of which protocol was being utilised.
Again in test 2 S-MAC and T-MAC performed well with lower energy consumption vs ZigBeeMAC. S-MAC again had the lowest average energy consumption however T-MAC showed better performance above the 30 Mhz sample rate. A reason for this could be that T-MAC can effectively utilise adaptive duty cycles entering a sleeping state once the transmission is finished instead of after a fixed period (Halkes, van Dam, & Langendoen, 2005). This, in theory, would be more effective at higher sample rates where transmission periods can be shorter due to more data being transmitted over the same period.

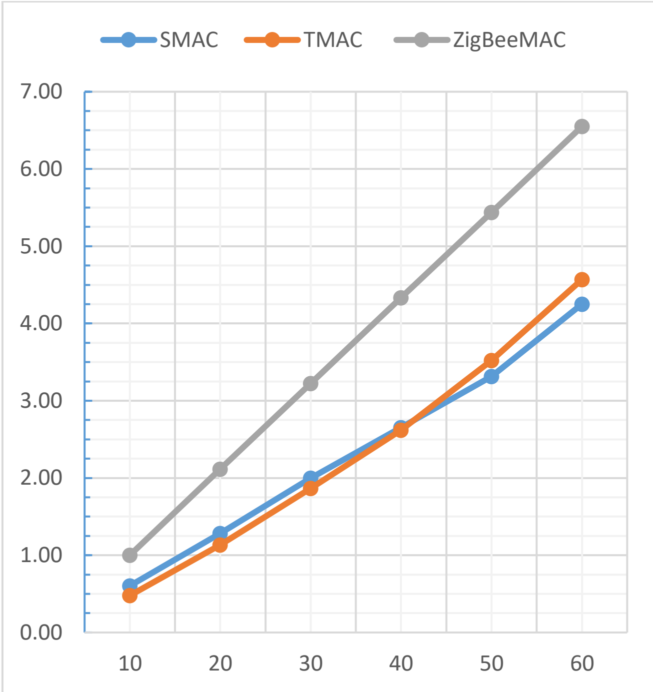

Figure 3 - Energy Consumption Vs Node Density - CC1000

Test 3 (Table 4) looked at the energy consumption vs node density between 10 and 60 at intervals of 10 using the CC1000 radio specification. Both S-MAC and T-MAC perform similarly when compared. SMAC did have a slightly lower average energy consumption at 2.35 (3 sf) compared to 2.36 (3 sf). ZigBeeMAC again performed worse with an average of 3.78 (3 sf). Both S-MAC and T-MAC utilise message passing to reduce contention latency for sensor-network applications (University of Southern California, 2002). This can be beneficial to sensor-network applications that require store-and-forward processing as it can reduce wait times and bottlenecks within the network minimising the energy consumption.
Increased node density will also mean more possible collision zones. For every collision in a reliable network, a packet must be resent to ensure that a transmission is completed. In a WSN this can result in wasted energy. ZigBeeMAC employs a Direct Sequence Spread Spectrum system to overcome

interferences and collisions. However, if a ZigBeeMAC packet collides with another ZigBeeMAC packet then both packets are always lost (Kumar, 2020). In an isolated WSN Direct Sequence Spread Spectrum system is rendered ineffective.

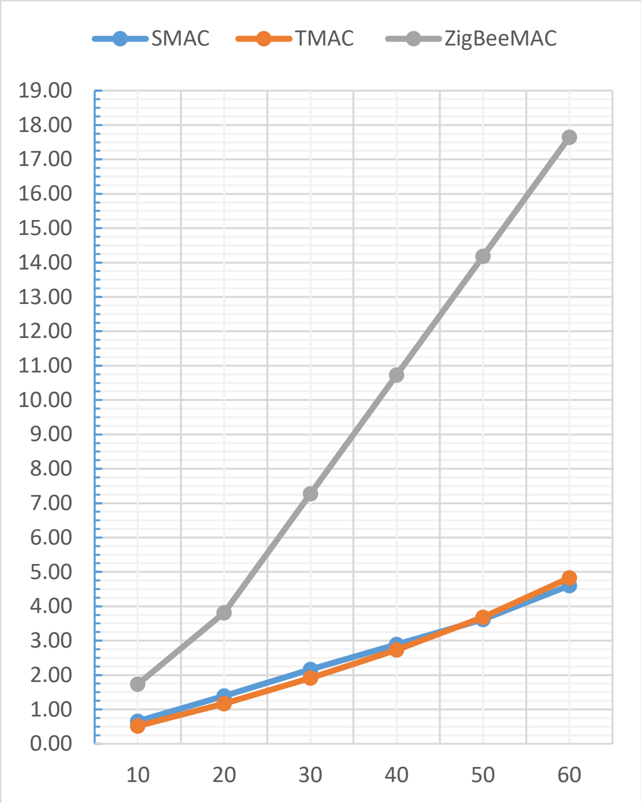

Figure 4 - Energy Consumption Vs Node Density - CC2420

Test 4 (Table 5) looked at the energy consumption vs node density between 10 and 60 at intervals of 10 using however it used the CC2420 radio specification. It again showed higher energy consumption for all protocols but, caused ZigBeeMAC to drastically increase its energy consumption. This could be higher due to ZigBeeMAC not utilising idle or sleep time like S-MAC or T-MAC. This means that the higher power consumption of CC2420 would mean that more energy is used over the same period compared to CC1000.

V. Future Study

It is recommended that further testing is required with a greater range of density to see how S-MAC and T-MAC perform. This is to investigate if T-MAC would outperform S-MAC in larger networks therefore potentially changing the views on what protocol had a better overall performance from S-MAC to T-MAC.

VI. Conclusion

S-MAC and T-MAC performed similarly within each of the tests, this should be expected as T-MAC was created using S-MAC as a base in an attempt to remove the faults that S-MAC had. It can be questioned whether T-MAC was an improvement on S-MAC as in the tests performed S-MAC showed on average a better performance in terms of energy consumption. However, it can also be said that T-MAC would've performed better with a larger network as results showed that it began to consume less energy than S-MAC in the later stages of each test. Therefore, it can be said that S-MAC would be the best choice for small networks with low data transmission rates as it performed the best when the network utilised a lower sample rate and lower network density. For larger networks or networks with high data transmission rates, T-MAC would be suitable as it performed the best with higher density and sample rate. ZigBeeMAC showed the worst overall performance throughout all the tests, this could be due to it not utilising idle or sleep modes wasting a large portion of the energy it was provided. However, ZigBeeMAC was the most consistent over all the tests, as it had the lowest variance between increments. This would make it the most reliable choice for networks that require steady power consumption with little to no fluctuation as it is the most predictable of the protocols. Overall, S-MAC would be the protocol of choice for a network like the one tested.

VII. References

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VIII. Appendix

Table 2

Test 1 Sample Rate	**10**	**20**	**30**	**40**	**50**
SMAC	5.093	4.574	4.328	4.345	4.13
TMAC	8.434	5.886	4.804	4.38	4.023
ZigBeeMAC	6.608	6.594	6.579	6.565	6.559

Table 3

Test 2 Sample Rate	**10**	**20**	**30**	**40**	**50**
SMAC	5.336	4.864	4.641	4.627	4.461
TMAC	7.148	5.321	4.554	4.252	4.003
ZigBeeMAC	11.355	11.367	11.37	11.368	11.367

Table 4

Test 3 Node Density	**10**	**20**	**30**	**40**	**50**	**60**
SMAC	0.604	1.282	1.999	2.652	3.314	4.251
TMAC	0.478	1.134	1.866	2.619	3.523	4.569
ZigBeeMAC	1	2.113	3.224	4.332	5.44	6.551

Table 5

Test 4 Node Density	**10**	**20**	**30**	**40**	**50**	**60**
SMAC	0.657	1.391	2.166	2.886	3.615	4.602
TMAC	0.519	1.17	1.913	2.729	3.686	4.825
ZigBeeMAC	1.734	3.816	7.273	10.729	14.186	17.643