base station. If the base station is far away from the nodes, this communication require high transmit power from each node as total energy consumption is proportional to d^2, the transmission distance. In MTE, nodes route data destined for the base station through intermediate nodes (as referred to Eq.1). LEACH is a clustering based approach which shows better performance compared to two other approaches (Eq.2).

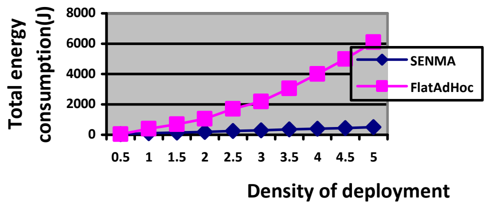

Figure 5. Total Energy Consumption

Figure 5 shows the total energy consumption over density of network for two different protocols, namely flatAdHoc network and SENMA [14]. SENMA deploys mobile agents(Eq.5&6) for communication with the base station in which mobile agents are powerful hardware units which can be an aerial vehicle or ground vehicle. In this architecture, mobile agents are responsible to convey sensor data to the base station. Whereas in flatAdHoc architecture (Eq.1), sensor nodes are continuously consuming energy in order to route data from neighbor nodes. As seen in the figure 5, the deployment of mobile agent consumes lesser energy compared to flat architecture using multihop routing. This can be useful results to benchmark with the architecture proposed in this paper deploying mobile agent for routing as well as energy harvesting.

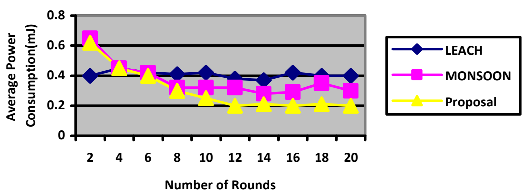

Figure 6. Average Power Consumption

Figure 6 shows average power consumption for three different protocols in which LEACH is a clustering based (Eq.3) approach, MONSOON [15] is a biologically inspired framework that consists of agents and middleware platform. The proposed framework (proposal)(Eq 5&6) implements sensing data collection applications with each node deploying a Sensing Agent (SA) with a randomly-generated behaviour policy. Based on the results presented with the mathematical analysis and comparison with other research works, the order of energy consumption from the highest to the lowest is: Direct –> MTE/Flat (multihop) -> LEACH (cluster) -> SENMA/proposal (mobile) (figure 7).

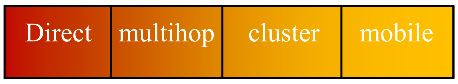

Figure 7. Flow of energy consumption

It is proven that mobile agent consumes the least energy for routing sensor data to the base station. And direct communication consumes the most energy for communicating sensor data to the base station. Direct transmission may not be a viable solution to reduce energy consumption in sensor networks. As seen in Eq.3, energy consumption will be affected by the transmission distance and energy consumption of nodes further away from the base station is four times more than nodes closer. These increases linearly as the radius increases and the energy consumption will be proportional to d^4 after the threshold value of transmission distance. Using a cluster head approach, sensors are only responsible for sensing the event and relaying data to the cluster head. Tremendous energy is saved as sensor nodes do not take part in routing and transmission of data as energy consumption is directly proportional to transmission distance. But as cluster head selection is on a rotational basis, sensor nodes would eventually deplete energy when it becomes the cluster head as it has to receive and send data from other nodes. Moreover based on Eq. 2 energy consumption using clustering approach is also affected by the width of the network since cluster head has to communicate using longer distance. Multihop communication ensures delivery of data as the data is forwarded by intermediate nodes. But multihop approach causes routing holes as nodes closer to the base station are heavily utilized and deplete energy quickly. The mobile agent based approach should be able to overcome the problem encountered by multihop as energy consumption in multihop is dependent ($2L^2$) whereas in mobile approach it is dependent on (L^2). The discussion in the following section proves that energy consumption using mobile approach is two times lesser than multihop routing.

6. Energy consumption and lifetime of mobile approach

Theorem 1 : Total energy consumption using mobile agent is lower bounded by $1/2e_c$, where e_c is energy consumed by multihop routing

Proof:Assume $\hat{c} = Energy_{cpu}$ $\quad \text{Ә} = Energy_{elec}$ $\quad \mu = Energy_{amp}$

energy consumed by mobile $e_m = \frac{aL^2}{\pi r^2} (\mu X H^2 + \hat{c})$

energy using multihop $e_C = 2aL^2 (\mu X d^2 + \text{Ә} + \hat{c})$

$$\pi r^2$$

Looking at e_C *and* e_m , $e_C > e_m$ or $e_m < 1/2\, e_C$ *since* $H < d$ *and* $e_C = ½\, e_m$ whereby e_C *is depending on distance H and* e_m depending on distance d,

Therefore,

$e_m < ½\, e_c$ (energy mobile is lower bounded by ½ energy multihop)

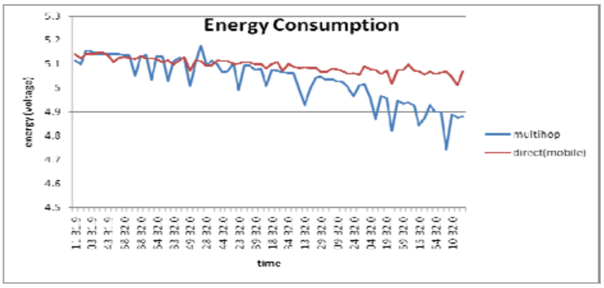

Figure 8: Energy consumption per node

Figure 8 outlines the results obtained from experiment using real sensors with each sensor boards attached to the standard battery. The energy consumption per node is traced by deploying the network in a multihop mechanism. The results obtained shows that mlutihop communication consumes more power and the energy in terms of voltage drops significantly as compared to direct communication. In this case the direct communication is configured as mobile architecture. Whereas figure 9 energy consumption for nodes placed near the mobile agent as well as nodes further away from the mobile agent. This shows that distance between mobile and sensor node is crucial for energy analysis.

Theorem 2: The lifetime of a node inversely proportional to distance H (between sensor node and mobile agent) and network width.

Proof

initial energy of a node = ***E***

energy per node using mobile agent = e_C

Therefore the lifetime of a node

$$= E / e_C$$

And assuming

$$e_C = \frac{aL^2 (\mu X H^2 + \ni) + ĉ}{\pi r^2}$$

$$\textbf{and lifetime per node} = E \Big/ \frac{aL^2 (\mu X H^2 + \ni +) + ĉ}{\pi r^2}$$

$$= \frac{\pi r^2 \;\; (E)}{aL^2 (\mu X H^2 + \ni +) \;\; ĉ}$$

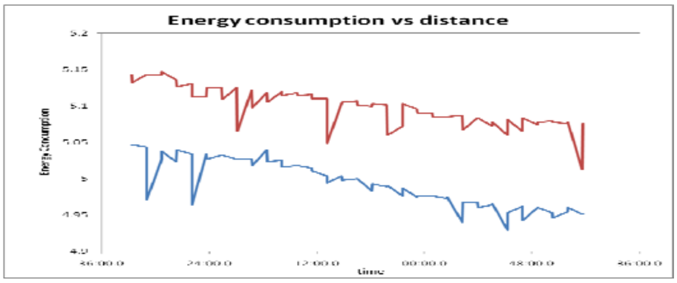

Figure 9. Energy consumption per node for different distance

7. Case Study: Illegal Immigration Detection

The mobile agent based approach discussed above will be applied into a prototype development into the illegal immigration detection system to prove with more applicable results. In line with the concern on protecting the country against illegal immigration and threat, a new mechanism using mobile wireless sensor technology is proposed. It is a self-healing wireless sensor network to detect any illegal immigrant moving into the country via forest or borders. This is specifically applicable immigrants entering the country through forest borders. I t is predicted that most of the refugees and immigrants from Myanmar are entering the country through Malaysia-Thailand border. The sensor technology proposed is intelligent enough to detect any movements by using image processing techniques such as motion sensors, vision sensors and sound sensors to further analyze the profile.

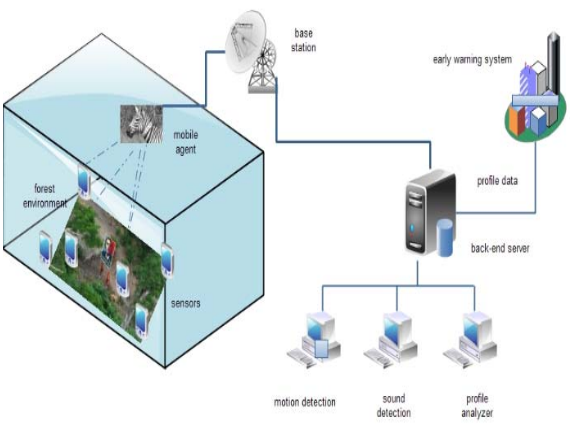

Figure 10. Illegal immigration system using mobile sensors

This is considered as micro-level technology that can detect any events in a smaller scale using image processing techniques as compared to remote sensing technology which is unable to detect events hidden from the satellite view. This technology works by static sensors being deployed to dynamically form a perimeter of network around the forest to detect any events as mentioned above. The sensed data is then forwarded to mobile agents (sensors) which are within the proximity of the area of the sensors. The mobile agent in this context works as a middleware to collect data from the static sensors and forward it to a base station for further action or early warning. Mobile agents can be aerial vehicles, ground vehicles with terminals and power generators that can hop around the network or it can be an airplane flying above the sensor field (airborne). Mobile agents do not need to be present all the time along with static sensors; they are only needed when it is necessary to collect data. Moreover mobile agents should have high data rate connection to base stations allowing faster dissemination of data.

Mobile agents are proposed in this context to shift away the processing and routing complexity from static sensors which are energy constrained. The use of optical and radar remote sensing (airborne sysnthetic aperture radar) is gaining popularity. Optical remote sensing has its disadvantage as it is restricted by clouds, haze and mist especially in high mountains. So a new technology using Mobile Wireless Sensor Technology can be a potential solution to combat the issues and problems discussed above. This research can even contribute to areas that need monitoring and early warning such as preserving natural resources, illegal logging, fire protection, soil erosion, tsunami warning, earthquake and others. Surveillance system could be another potential area where this research can be applied. In this case a security guard carrying a sensor embedded mobile device can be the agent collecting data from static sensors attached to buildings or forest for surveillance detection.

8. Conclusion

The proposed architecture in this paper using mobile agent as communication and energy harvesting agent should be a better solution for energy efficient operation in sensor networks. This can be further exploited by performing simulation of the protocol mentioned in section 4 and comparing with other protocols discussed in section 5. In future mobile agent (sensors) should take the role of static sensors for forwarding sensor data to the base station as well as a source for energy harvesting and scavenging.

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