INTRUSION K-COVERAGE IN WIRELESS SENSOR NETWORKS

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Abstract: One of the main applications of Wireless Sensor Networks is surveillance and monitoring. Providing and maintaining the required coverage over the area of an intrusion (or other events of our choice) is of great importance. The network should be able to provide different levels of coverage based on application needs and reconfigure itself while ensuring energy efficiency. In this paper we present a dynamic approach to provide asymptotic k-coverage over the area of an intrusion. This is a probabilistic approach which creates full coverage over the surveillance zone and provides k-coverage over the area of an event. Our simulations show that this approach is able to provide the requested coverage while consuming less than a third of the static approaches. Also due to probabilistic nature of this approach communication overhead is much lower than deterministic methods.

1 INTRODUCTION

Wireless Sensor Networks usually consist of a large number of small sensor nodes with limited energy source which use a low-bandwidth wireless radio for communication. A sensor node can only last 100-120 hours on a pair of AA batteries in the active mode and battery capabilities are only doubled every 35 years(Ye et al., 2002). This makes energy efficiency the main challenge in application design for sensor networks.

Putting sensors to periodic sleep in dense sensor networks has been suggested as a way to increase the network longevity. (Wang and Xiao, 2005) Sensor nodes in the sleep mode consume only 0.1% of the energy consumed in the active mode(Kumar et al., 2006). Low duty cycle results in higher delay, lower coverage and connectivity in exchange for power efficiency. Nodes in the sleep mode are unable to detect events in their sensing range and are unable to receive or forward any packets (MAC layer can have a different duty cycle from the sensing device which we will discuss later).

Several scheduling schemes have been suggested to minimize the effect of sleeping nodes on the desired parameter (delay, connectivity, etc) in the network (Lu et al., 2005), (Wang et al., 2003). Coverage is one of the important parameters that are affected by the scheduling scheme.

In surveillance and monitoring applications, it is usually required to have at least *k* sensors cover every point in the surveillance zone (*k*-Coverage). In dense networks (Ye et al., 2002) where there are more than *k* sensors present in each area, sensor nodes are put to low duty cycle. This raises the question of which nodes should be active in each cycle in order to maintain the same coverage (Kumar et al., 2006), (Abrams et al., 2004) while other nodes in the area go to sleep. It means that we need a coordination function (Chen et al., 2002) between neighbor nodes to determine the state of each node in each cycle in a way that the total

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number of sensors to cover the neighborhood is approximately *k*.

The need for a mechanism to dynamically configure the coverage provided according to the needs of the application was mentioned in (Wang et al., 2003). Dynamic configuration of sensor network helps the network to adapt to different applications' requirements and maximizes the energy efficiency.

2 RELATED WORKS

(Tian and Georganas, 2002) present a deterministic method for providing coverage on the surveillance zone. This method guarantees that the original sensing coverage is maintained after the redundant nodes are turned off. This approach assumes that all nodes have it's and it's neighbors location information. It also requires techniques to estimate the direction of the received signal which may require more than one antenna.

(Wang Rui et al., 2006) presents an Ant Colony method for self organization of sensor networks. Each sensor is regarded as an immobile ant. Each ant at each cycle wakes up with probability . Upon detection of an event the ant lays pheromone which is diffused to its immediate neighbours. Neighbour ants that receive this pheromone will increase the probability of waking up at the next cycle. Based on the accumulated amount of received pheromone each node calculates the probability of going to sleep in the next cycle. This method increases the percentage of useful nodes (nodes that have detected an event) in the network. This approach doesn't provide guaranteed detection of events.

Most deterministic methods such as (Wang et al., 2003),(Tian and Georganas, 2002),(Ye et al., 2002) use an *eligibility rule* to turn off the redundant nodes in the area. In order to determine which nodes can be turned off they either require the location information of their neighbors or they need to probe the area for other active sensors. This imposes a higher communication and computation overhead in comparison to probabilistic approaches.

In (Kumar et al., 2006) boundary conditions to have *k*-coverage in a mostly sleepy network in three distributions (Grid, Random Uniform, Poisson) are presented. We use the equations presented in (Kumar et al., 2006) to dynamically calculate the probability of waking in the sensor nodes which is discussed further below.

3 DYNAMIC K-COVERAGE

3.1 Problem Definition and Assumptions

A set of N sensors $s = \{s_1, s_2, ..., s_n\}$ in a two dimensional area *A* are distributed using Random Uniform Distribution, Grid Distribution or Poisson distribution. All sensors have the same sensing range *r*. Sensor nodes have periodic sleep/awake cycles in which a sensor node turns its sensing device on or off. Duty cycle of the transmission device is controlled by the MAC protocol.

Duty cycle of sensing device in turn follows the scheme by the wakeup probability in each cycle which our scheme assigns to each node.

Our assumption about number of deployed sensors, probability of parallel occurrence of events in the network and availability of location information are similar to (Yahyavi et al., 2008).

Similar to (Yahyavi et al., 2008), we provide 1-coverage over the entire surveillance zone. If an intruder in the surveillance zone is detected the wakeup probability is adjusted to provide asymptotic k-coverage in the *effective area* of the intruder (a circle around the intruder with radius , nodes in this area are able to detect the intruder if they are active). We use boundary conditions presented in (Kumar et al., 2006) to determine the wakeup probability required for different levels of coverage.

Consider that a function $\phi(np)$ is slowly growing if it is monotonically increasing and $O(\log(\log(np)))$, and goes to infinity as $n \to \infty$. Let

$$c(n) = \frac{np\,\pi r^2}{\log(np)} \quad (1)$$

For the Random Uniform Distribution and Poisson Distribution, for some $\phi(np)$ if

$$c(n) \geq \frac{\phi(np) + k\log(\log(np))}{\log\log(np)} \quad (2)$$

Then all the points are almost always *k*-covered as *n* approaches infinity (Kumar et al., 2006). Where *n* is the number of sensors deployed, *p* is the probability of being active in each cycle, *r* is the sensing radius of each sensor, and *k* is the level of coverage. For Grid Distribution for some $\phi(np)$ if

$$c(n) \geq 1 + \frac{\phi(np)(1+\sqrt{p\log(np)}) + k\log(\log(np))}{\log(np)} \quad (3)$$

Then all the points are almost always *k*-covered as *n* approaches infinity. (Kumar et al., 2006)

Similar to (Kumar et al., 2006), since we assumed that the number of deployed sensors is sufficiently large, boundary conditions (2) and (3) hold. These boundary conditions are used to calculate the required wakeup probability of nodes (for a fixed number of deployed nodes) to provide a certain level of coverage. Goal is to find the minimum probability that satisfies above boundary condition for the required *k*. Minimizing the satisfying probability lowers the number of active sensors in each cycle and results in higher energy savings (while providing *k*-coverage).

3.2 The Basic Model

In order to be able to detect any events in the surveillance zone we need to have at least one sensor cover every point in the surveillance zone. To calculate the required wakeup probability to achieve 1-coverage from conditions (2) and (3) each node should know the distribution type and the number of deployed sensors. These parameters can be flooded into the network after it has been deployed. The required *k* should also be flooded in the network along with these parameters. In case these parameters change (the required *k* or *n*) they should be re-flooded into the network.

All nodes primarily set their wakeup probability to 1-coverage level. As an intruder enters the area the only active sensor in that area issues a broadcast message to alert neighbor nodes about the intruder. Since MAC layer does not follow our sleep schedule the detecting node may not be able to send the ALERT message immediately and will have to wait till the active period of MAC layer begins. All neighbor nodes that hear this broadcast message increase their wakeup probability to *k*-coverage level. Therefore the number of active sensors in the next cycle is increased to approximately *k* nodes.

In case an active node with wakeup probability level *k*-coverage doesn't detect an intruder it reduces its wakeup probability for the next cycle to 1-coverage level.

3.3 Misplaced K-Coverage Problem

Since only nodes in the communication range of the first node that has detected the intruder can hear its broadcast message and set their wakeup probability to *k*-coverage level, some nodes in the effective area of the intruder may not hear the ALERT message. Also the intruder might be moving and the detecting node may not be able to send the ALERT message until the end of its MAC layer sleep period. Therefore all nodes in the *effective area* of the intruder may not hear the ALERT message. We call this the *misplaced k-coverage problem* (Figure 1.a).

To address this problem, we present three solutions; each one is more suitable for a different situation and application.

3.3.1 Covered Effective Area Estimation

One of the methods to solve the misplaced *k*-coverage problem is to choose a higher wakeup probability so that the number of active nodes in the effective area of the intruder is increased. This solves the misplaced *k*-coverage problem but increases the energy consumption in comparison to the basic model. The number of sensor nodes that are in the effective area of the intruder and in communication range of the detecting node is related to the movement speed of the intruder and the density of nodes in the area. The faster the intruder moves the less the number of nodes in the effective area that can hear the ALERT message.

If the sensor node is able to determine the location of intruder, the actual number of sensors that can hear the ALERT message can be calculated:

$$s = \int_0^{r-\frac{d}{2}} 4\sqrt{r^2 - x^2}\,dx =$$

$$2r^2 \sin^{-1}\left(1 - \frac{d}{2r}\right) - r^2 \sin\left(2\sin^{-1}\left(1 - \frac{d}{2r}\right)\right) \quad (4)$$

Where *d* is the distance from intruder to the sensor node at the time of sending the ALERT message.

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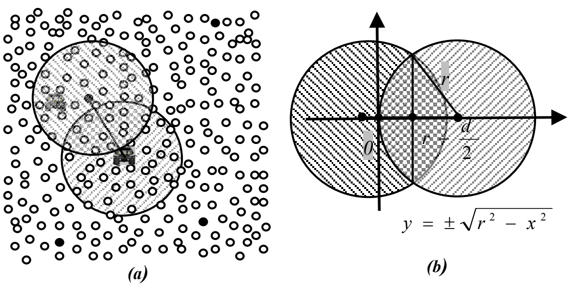

Figure 1: *(a)* A randomly distributed wireless sensor network and misplaced K-Coverage problem, *(b)* the Effective Covered Area.

Therefore the number of sensors in the range of ALERT message is:

$$\Pr(k-\text{coverage}) = \frac{k}{s \times \rho} \quad (5)$$

Where is the area that is covered by ALERT message and ρ is the density of nodes $(\frac{n}{A})$. In our simulations we assumed that the sensor node does not have location and in a pessimistic guess considered that only 75% of the effective area is covered by the ALERT message.

3.3.2 Delayed Reduction

As mentioned in our basic model we reduce the wakeup probability level of a sensor that has heard ALERT message to 1-coverage level in case it does not detect the intruder in the following cycle.

In the delayed reduction model each node calculates and store k wakeup levels $\{1,2,...,k\}$. In case the sensor node does not detect an intruder in the cycle after receiving an alert message it reduces its wakeup probability by only one level. Since the node doesn't decrease its level to 1-coverage immediately we call this approach the delayed reduction method.

This method is most useful when several intrusions with the same movement pattern occur. For example in border monitoring usually several consecutive intrusions occur in the same area. In this model after an intrusion occurs the network in the intrusion's area remains alert for the possible consecutive intrusions.

3.3.3 Diffusion Model

In the diffusion model all active nodes that have heard an ALERT message will rebroadcast the ALERT message. In the Diffusion Model the ALERT message also contains an alert level. Nodes that hear this message set their wakeup probability level to the level determined by the message.

In case a node detects the intruder it broadcasts a message with alert level k otherwise it reduces the alert level received by one level and rebroadcasts the alert message. Similar to Delayed Reduction model nodes decrease their wakeup probability level by one level in each cycle.

In case a node receives several alert messages it chooses the maximum alert level received as its alert level. If a node receives an alert level lower than its current wakeup probability level it will not rebroadcast the ALERT message since all its neighbor nodes already have equal or higher wakeup probability level. This situation can happen in case there is more than one intruder in the sensing area and it has already caused higher wakeup probability level in that area (Figure 2).

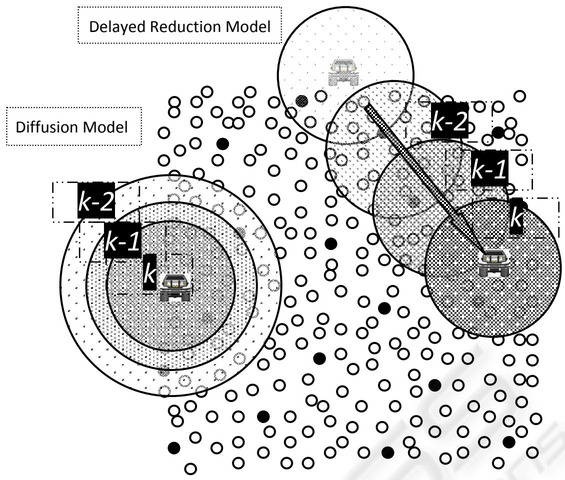

Figure 2: Wakeup probability levels in Diffusion Model and Delayed Reduction Model.

This approach is more suitable for situations where the intruder's movement is unpredictable and high coverage on the intruder is required. This approach provides higher coverage and reliability in exchange for higher messaging and computational overhead. The probability level in the intruder's effective area is almost always at least k.

Several methods can be used to reduce the messaging overhead of this approach. For example if the number of ALERT messages that a node hears is more than a certain threshold it does not broadcast an ALARM message. In case location information is available ALERT messages from nodes closer than a certain distance will not be rebroadcasted.

3.4 MAC Support

Several MAC protocol with energy saving features have been proposed. Sensor nodes have different energy consumptions in off, listening, receiving and transmission modes (Chen et al., 2002). Putting the transceiver to sleep also reduces the energy loss due to overhearing avoidance.

Our approach requires support from the MAC layer to make sure that neighbor nodes can hear each other's ALERT messages. IEEE 802.11 always keeps the radio transceiver active which allows the sensor node to send an ALERT message as soon as an intruder is detected. On the other hand IEEE 802.11 has very high energy consumption. MAC protocols that have Sleep/Active periods should provide synchronous wakeup of neighbor nodes so that at the end of sleep period nodes are able to send the ALERT messages. S-MAC (Ye et al., 2004) and T-MAC (Dam and Langendoen , 2003) support such synchronous wakeups. We assume that reader is familiar with S-MAC (For further information please refer to (Ye et al., 2004)).

Since after the initial synchronization period in S-MAC the SYNC period is rarely used (to resynchronize the schedules) we use this period for our broadcast messages. In case there is a SYNC packet waiting to be sent we can piggy back our ALERT on the SYNC message. Otherwise an independent ALERT message is created and sent (RTS/CTS period can be similarly used).

In case the MAC protocol of our choice doesn't support synchronized wakeups of neighbor nodes, in order to ensure that all neighbor nodes hear the broadcast message, the node has to wake up at the wakeup time of each one of its neighbors and rebroadcast the ALERT message which increases the energy consumption.

4 ENERGY CONSUMPTION AND COVERAGE ANALYSIS

Dynamic reconfiguration of wakeup probability in the area of an intrusion can provide significant energy savings. Since the whole surveillance zone is not *k*-covered number of active sensors in the network is much less therefore overall energy consumption of the network is substantially decreased. Information required to calculate the wakeup probability levels should only be flooded once in the network. Probability levels are also calculated and stored once at the beginning of network's deployment.

In the Effective Covered Area Estimation and Delayed Reduction model the only messaging overhead for dynamic reconfiguration is the ALERT message sent by the first detecting node. Since the ALERT message is a very small packet and may be piggybacked this overhead is negligible. On the other hand in Diffusion Model each node rebroadcasts the ALERT message with a lower alert level which poses higher messaging overhead.

Since our approach is probabilistic it doesn't need any location or probing information unlike (Wang et al., 2003),(Tian and Georganas, 2002),(Ye et al., 2002) to provide the requested coverage. Also in case better and tighter boundary conditions for wakeup probability to provide *k*-coverage are found they can be easily replaced with current ones.

5 SIMULATION RESULTS

We evaluated different approaches presented in this paper by simulation. Sensor network is deployed in a $150m \times 150m$ area. Sensing and communication range of nodes is 4m. Higher communication range than sensing range helps the ALERT message to cover a larger area. Static *k*-coverage calculates the wakeup probability needed to provide *k*-coverage and assigns this probability to all of the deployed nodes. This method is compared to our dynamic *k*-coverage approach and different solutions to solve the *misplaced k-coverage problem* are compared. Each simulation is run ten times and the requested coverage in all simulations is 8-coverage (some simulation results are not included due to space limitations).

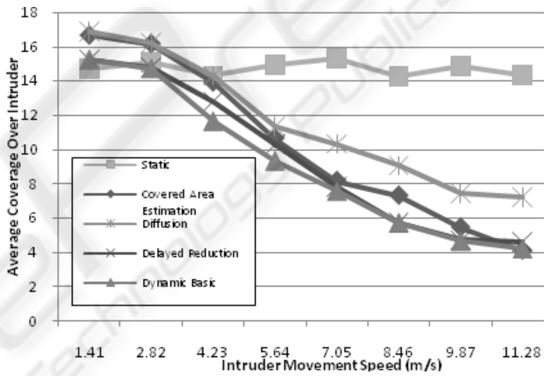

Figure 3: Average Coverage over an intruder for different speeds.

Figure 3 shows how average coverage provided by each method changes as the movement speed of an intruder increases. As expected Static k-coverage has the highest stability at the cost of higher energy consumption. *Diffusion Model* and *Covered Area Estimation* both provide high coverage for low movement speeds but as the speed increases *Covered Area Estimation*'s average coverage shows a sharp decrease. This is because actual covered area by ALERT message becomes smaller than our guess. Diffusion Model has a more stable behaviour which comes at the cost of higher messaging overhead. The effect of *misplaced k-coverage problem* on the coverage provided is clear.

Figure 4 compares the average coverage provided over an intruder by different approaches. It also shows that average coverage for these methods doesn't change as the number of nodes increases. This means increasing the number of deployed nodes will directly reduce the wakeup probability and increase network longevity.

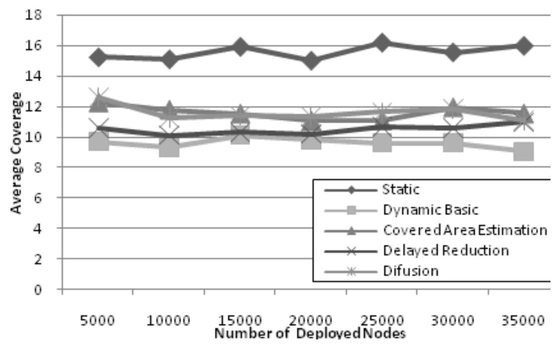

Figure 4: Average coverage over an intruder for different number of nodes.

Figure 5 shows the average number of active nodes in each cycle. As shown, to provide the requested coverage always a fixed number of nodes are required which means by increasing the number of deployed nodes wakeup probability is reduced. The main reason to use dynamic k-coverage is its power efficiency. The number of active nodes in each cycle is a very good measure of energy consumption of each method. All dynamic approaches wake less than a third of the static approach.

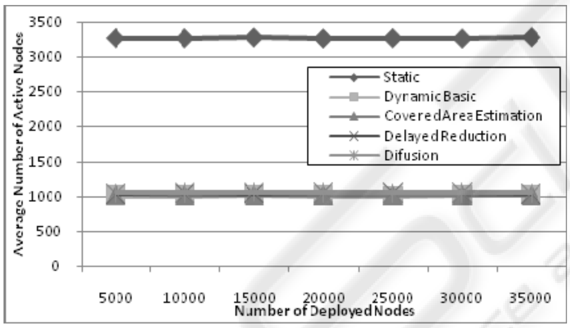

Figure 5: Average number of active for different number of nodes.

6 CONCLUSIONS

In this paper we presented a dynamic approach to provide *k*-coverage over the area of an intrusion. This approach provides 1-coverage over the surveillance zone and k-coverage over the area of an intrusion. Several solutions for misplaced k-coverage problem which rises due to the dynamic nature of approach are discussed. Each solution is more suitable for a different kind of application. Our simulations show dramatic improvement in energy consumption of the network which results in higher network lifetime. Our approach is completely compatible with current popular MAC protocols in WSNs. In this approach nodes do not need any location information and due to its probabilistic nature, minimal communication to provide *k*-coverage is needed.

REFERENCES

Akyildiz I.F., Su W., Sankarasubramaniam Y., and Cayirci E., 2002. "Wireless sensor networks: a survey," *Computer Networks*, vol. 38, pp. 393-422.

Chen B., Jamieson K., Balakrishnan H., and Morris R., 2002, "Span: An Energy-Efficient Coordination Algorithm for Topology Maintenance in Ad Hoc Wireless Networks," *Wireless Networks*, vol. 8, pp. 481-494.

Dam T.V., and Langendoen K., 2003. "An adaptive energy-efficient MAC protocol for wireless sensor networks," In *Proceedings of the 1st international conference on Embedded networked sensor systems*, Los Angeles, California, USA: ACM, pp. 171-180.

Kumar S., Lai T.H., and Balogh J., October 2006. "On k-coverage in a mostly sleeping sensor network," *Wireless Networks*.

Lu G., Sandagopan N., Krishnamachari B., and Goel A., "Delay efficient sleep scheduling in wireless sensor networks, 2005." *INFOCOM 2005. 24th Annual Joint Conference of the IEEE Computer and Communications Societies.* Proceedings IEEE, vol. 4, pp. 2470-2481 vol. 4.

Tian D. and Georganas N.D., 2002."A coverage-preserving node scheduling scheme for large wireless sensor networks," *in Proceedings of the 1st ACM international workshop on Wireless sensor networks and applications*, Georgia, USA: ACM, pp. 32-41.

Wang L. and Xiao Y., 2005. "Energy saving mechanisms in sensor networks," Broadband Networks, 2005 2nd International Conference on, pp. 777-785.

Wang Rui et al., 2006. "Swarm Intelligence for the Self-Organization of Wireless Sensor Network," In IEEE congress on Evolutionary Computing, p. 838-842.

Wang X., et al. 2003, "Integrated coverage and connectivity configuration in wireless sensor networks," *Proceedings of the 1st international conference on Embedded networked sensor systems*, pp. 28-39.

Yahyavi A. et al., 2008. "DyKCo, Dynamic K-Coverage in Wireless Sensor Networks," *IEEE International Conference on Systems, Man, and Cybernetics*, to appear.

Ye F., Zhong G., Lu S., and Zhang L., 2002. "PEAS: a robust energy conserving protocol for long-lived sensor networks," Network Protocols, 2002. Proceedings. 10th IEEE International Conference on, pp. 200-201.

Ye W., Heidemann J., and Estrin D., 2004. "Medium access control with coordinated adaptive sleeping for wireless sensor networks," *IEEE/ACM Trans. Netw.,* vol. 12, pp. 493-506.