# Random Walks with Jumps in Wireless Sensor Networks

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***Abstract*—Random Walks have been proposed for information dissemination/discovery in Wireless Sensor Networks. In this work we propose the Random Walk with Jumps model as an improvement on the Random Walk without Jumps for sparse graphs. Our proposal features the incorporation of 'jumps' (with random direction and length) in the otherwise simple random walk movement throughout the graph of sensor nodes. Our proposal is tested via simulations and is shown to outperform the Random Walk without Jumps both in the average number of steps required to partially cover the network and in the overall energy consumption of the nodes in the network.**

## I. Random Walk without Jumps

Researchers have recently proposed the use of Random Walks in various networking fields, such as Wireless Sensor Networks or P2P networks. The random walk methodology is proposed as a means of executing different networking tasks, such as query processing [1], sensor data collection [2] or network sampling [3]. Primary reasons for the consideration of such randomized solutions are simplicity of the process, locality of computation and robustness to failure [4]. These particular characteristics apply well to the highly populated and dynamic emerging networking structures such as Wireless Sensor Networks or P2P networks.

The Random Walk without Jumps on a graph can be described by the simple process of visiting the nodes of the graph $G$ in some sequential random order. The process begins at a random node $v \in V$ of the graph $G(V,E)$ and at each step the packet is forwarded to a neighbor of the current node $u \in V$ uniformly at random. In particular, if $\delta(v)$ denotes the degree of node $v$, a neighbor $u$ is chosen with probability $P(v,u)$ equal to $1/\delta(v)$. for $(v,u) \in E$.

A property of random walks on graphs frequently examined in literature is the Cover Time $C$ of the walk. It is defined as the expected number of steps taken by a random walk to visit every node in $G$. Known results for the cover time of specific graphs vary from the best case of $O(nlog(n))$ to the worst case of $O(n^3)$. The best cases correspond to dense, highly connected graphs, such as the complete graph $K_n$ or the d-regular graph with $d > n/2$, where d is the average connectivity degree in the graph. When connectivity decreases and 'bottlenecks' exist in the graph, the cover time increases.

The process of a random walk is an uncontrolled process and therefore it may well be that the walk will go to a neighbor and return back to the same node after one step. Even if such a move were forbidden, one can not prevent it from happening after a few steps. Such revisits of already covered nodes are in fact so frequent, that they can significantly deteriorate the performance of the walk both in terms of progress of the covering process and in terms of wasted energy resources in the network.

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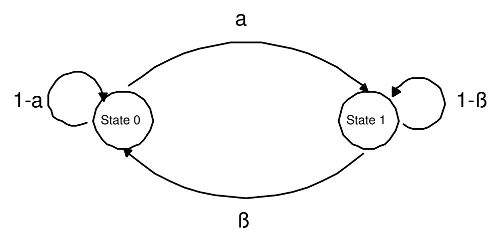


Fig. 1. Random Walk with Jumps Controls

## II. Random Walk with Jumps

In this work, we propose a methodology for accelerating short random walks in large networks of wireless sensors. We develop a scheme that will induce fewer re-visits to already covered nodes, this accelerating the covering of the network. Our scheme is based on the concept of 'jumps' of the walk within the network, where each jump will have a certain direction and length (measured in hop count). The direction and number of hops for each jump will be chosen randomly. It is expected that the addition of long jumps to the otherwise standard movement of the random walk will impact positevely on the performance of the walk on the graph towards achieving faster covering times and reducing the occasions of covered nodes re-visits.

The proposed scheme is based on the simple, 2-state markov chain depicted in figure 1. The state changes of the chain are executed at each step of the random walk and they govern the movement of the walk in the network. When the chain is in state zero, the walk behaves normally, i.e. it progresses according to the Random Walk without Jumps

TABLE I
SIMULATION NETWORK SETTINGS

| | |
|---|---|
| Network area (in units) | $10^6$ |
| Number of nodes | 20000 |
| Wireless comm. range (in units) | 25 |
| Av. connectivity degree | 39.27 |

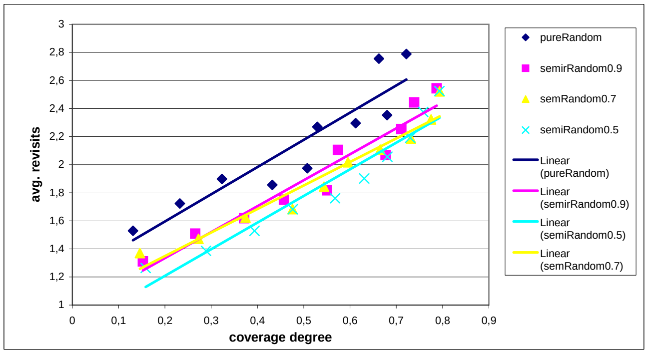


Fig. 2. Simulation Results

model. However, when the chain is in state one, the walk will execute a 'jump' with a given geometric direction that will be maintained for as long as the state does not change; the length of this directed jump will be shaped by the parameters of the Markov model. The parameters $\alpha$ and $\beta$ shown in the figure are the respective state transition probabilities which probabilistically rule the walk's movement.

## III. EXPERIMENTAL RESULTS

We tested the Random Walk with and without Jumps on a large Wireless Sensor Network using the Omnet++ simulator. A random geometric graph was created with parameters as summarized in Table I. The locations of the nodes were chosen uniformly at random within the given square area in both x- and y- directions. Nodes residing within the communication range of each other were connected with a link. To perform the random walk simulation, a RW packet was inserted into the network at a randomly chosen sensor node. Prior to each forwarding of the packet the state of the controlling markov chain was queried and a decision for the next hop neighbor was accordingly made.

Figure 2 depicts the results obtained after running both Random Walk models. For the Random Walk with Jumps model , the parameters $\alpha$ and $\beta$ were given values such that $\alpha$ would remain constant ($\alpha = 0.3$) and $\beta$ would be changing in order for the expected length of the jumps in the network to increase. We test the parameter values: 0.9, 0.7 and 0.5. In order to test the performance of short random walks, we chose to limit the amount of steps that the walk would be allowed to run. The limit on the maximum amount of steps was changed such that different coverage degrees would be reached in the network.

Each point in the figure represents an average over 5 runs for the given set of parameters. A first comment on the results is that the average number of covered nodes revisits is higher for the Random Walk without Jumps than for the Random Walk with Jumps. Furthermore it is straightforward that decreasing values of the $\beta$ parameter lead to steadily fewer average number of revisits, thus indicating that for longer average lengths of the jumps, the performance of the walk in terms of revisits is steadily improving. This result indicates that we can have significant gains in energy resources using the Random Walk with Jumps model because there are fewer wastes of energy due to reduced number of revisits to already covered nodes for a given coverage degree in the network.

A further point worth mentioning is that the Random Walk with Jumps process achieves better coverage degrees for a given maximum amount of steps of the walk in the network. Based on the results in Figure 2 we deduce that greater average expected lengths for the jumps in the walk lead to improved covering process of the graph of sensor nodes.

## IV. FURTHER PLANS

The results obtained by our simulations indicate that the Random Walk with Jumps is in fact achieving performance improvement over the Random Walk without Jumps in sparse graphs. Our plans for further work include analytical work on the new model and comparisons of numerical with simulation results.

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