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Design of cognitive algorithm based on data traffic control for underground accurate positioning system

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Abstract
In the existing accurate positioning system, a large amount of positioning data are uploaded to the ground control center, which often cause link congestion for the positioning system. The link congestion further degrades the positioning performance like real-time and reliability. In order to overcome the above disadvantages about the existing accurate positioning system, a novel cognitive algorithm based on data traffic control is proposed to reduce data traffic and avoid link congestion for the positioning system. The algorithm uploads location data only when target nodes are in motion, and the control center uses V-T algorithm to predict the complete trajectory of the target nodes simultaneously. Finally the simulation results show that the proposed algorithm applying to the accurate positioning system for mine coal can greatly reduce data traffic and don't degrade the trajectory tracking performance.
Keywords: ACCURATE POSITIONING; DATA TRAFFIC CONTROL; MINE COAL; COGNITIVE ALGORITHMS.

1. Introduction

With accurate positioning systems widely used in coal mines, they makes the ground control center can monitor the accurate location where miners are in real-time. When an accident occurred, the positioning system can provide important information to rescuers for rescuing the trapped miners.

Due to the harsh environment of the coal mine, data transmission rate is very low, even only a few tens of kB, between the ground control center and base station [1]. However, for tracking the target nodes in real-time, a lot of tracking data from base stations have to be uploaded to the monitoring center in the accurate positioning system for mine [2-5], and these tracking data consisted mainly of the location and other relevant information of the target nodes. A large amount of data uploaded from base stations is easily to block communication links, even bring link congestion. Once the link congestion occurred, the communication between the monitoring center and the base station would be interrupted, so that the monitoring center can not provide the location information of miners to rescuers in time when an accident occurred. Therefore, the reliability and real time tracking of positioning system can be improved by reducing tracking data to avoid communication link congestion.

In order to solve problems mentioned above, we propose a new cognitive algorithm to control data traffic in accurate positioning systems. In this cognitive algorithm, the base station proactively perceives the motion states of the target node, and determines whether or not it uploads the tracking data about the target node to the control center in according to the current state of the target node. In this work, the base station uploads the tracking data to the control center only when the target node's location has changed[6-8], so that the data quantity in positioning system is compressed to avoid link congestion, while the positioning accuracy for the target node likely declines. In order to compensate accuracy loss of positioning system due to compress the data quantity, we use V-T algorithm to predict the complete trajectory of the target nodes [9].

2. Cognitive Algorithm base on Data Traffic Control

Aim to decrease the data traffic generated by the accurate positioning system, a cognitive algorithm base on data traffic control is proposed in this work. .

What follows is the basic idea of the traffic control algorithm, in the positioning system, the base station periodically samples the location information of the target nodes and capture the tracking data, and the target nodes often stay two types of state-static and moving, we take different strategies to control data traffic according to the different state of target nodes. When the target node is stationary, its position at adjacent sampling interval almost has no change. Therefore, the base station doesn't upload the present tracking data about the target node to the control center and discards these useless tracking information, the control center predict the movement trajectory of the target node using the V-T algorithm; When the target node is moving, the base station regularly uploads the sampling tracking information about the target node to the control center in given sampling period. So that the cognitive algorithm effectively condense the data traffic generated by the positioning system. Meanwhile it will not degrade the trajectory tracking performance of positioning system. As shown in figure 1, it is the working process of the algorithm.

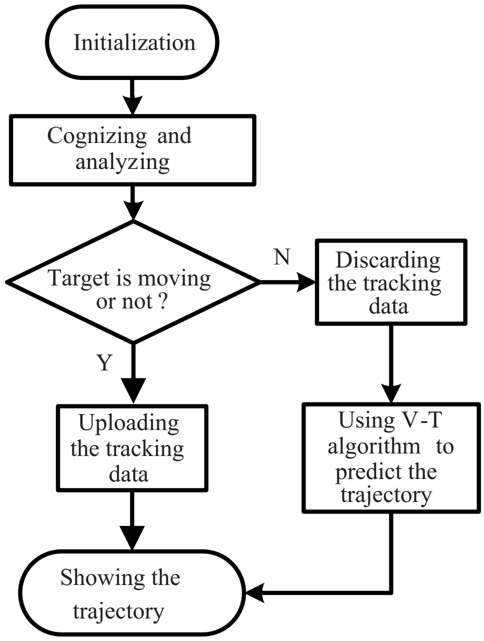

Figure 1. The working process of the cognitive algorithm

2.1. Analyzing the Motion State of the Target Node

In the proposed cognitive algorithm, the mobile state of target nodes is a key factor that affect the data traffic control efficiency is how to determine the present mobile state of the target node is static or not. However, the following parameters will determine the motion state determination of the target node, which are system positioning accuracy [10], the speed of target node and positioning interval.

Assume the true distance at time instant t_i between the base station and the target node is denoted by $D(t_i)$, and the measurement distance is denoted by $d(t_i)$, and the positioning error is denoted by $e(t_i)$. Then as discussed in [11, 12], the measurement range d(t_i) can be modeled as:

$$d(t_i) = D(t_i) + n_m(t_i) + NLOS_m(t_i) = D(t_i) + e(t_i) \quad (1)$$

$$e(t_i) = n_m(t_i) + NLOS_m(t_i) \quad (2)$$

Where the term $n_m(t_i)$ represents the measurement noise, and it is modeled as an identically distributed zero-mean white Gaussian variable, and the term $NLOS_m(t_i)$ represents the NLOS(non-line of sight) error, it is modeled as a positive random variable.

Assume the displacement of measurement distance in (t_i, t_{i+1}) is denoted by Δd_{i+1}.When the target node is stationary, Δd_{i+1} is calculated from Eq.1 as:

$$d(t_{i+1})-d(t_i)=e(t_{i+1})-e(t_i) \\ => \Delta d_{i+1}-\Delta e_{i+1} \quad (3)$$

$$\Delta e_{i+1}=e(t_{i+1})-e(t_i) \quad (4)$$

Where, the term Δe_{i+1} represents the difference of positioning error in (t_i, t_{i+1}).

Assume the positioning interval is denoted by T, and the true speed of the target node is denoted by v_i at time instant t_i. So the true distance $D(t_{i+1})$ at time instant t_{i+1} equals as:

$$D(t_{i+1})=D(t_i)+v_iT \quad (5)$$

When the target node is moving, the value of Δd_{i+1} is calculated from Eq. 1 as:

$$d(t_{i+1})-d(t_i)=v_iT+e(t_{i+1})-e(t_i) \quad (6)$$

Then according to Eq. 3 - Eq. 6, the value of Δd_{i+1} is calculated as:

$$\Delta d_{i+1}=v_iT-\Delta e_{i+1}=v_{mi}T \quad (7)$$

Where, assume the measurement speed of the target node is denoted by v_m, and v_m is proportional to v.

Assume the displacement of measurement distance between any two adjacent positioning points is denoted by Δd. The term A_{max} represents the system positioning accuracy. From Eq. 3 and Eq. 7, when $\Delta d > A_{max}$, namely the displacement of the target node within a positioning interval is greater than the system positioning accuracy, the base station is able to reliably determines that the target node is moving, and uploads the tracking data, otherwise discards the data.

When Δd is fixed, the system positioning accuracy is lower, the probability to meet $\Delta d > A_{max}$ is less, the base station can discard more positioning data; When the speed of target node and A_{max} is fixed, the positioning interval T is shorter, the probability to meet $\Delta d > A_{max}$ is less, the base station can discard more positioning data too. In these conditions, the base station can effectively decrease the data flow of positioning system.

2.2. V-T Algorithm

When the base station discards the positioning data at time instant t_i, the control center uses the value of V-T algorithm to replace the discarded positioning data. The value of V-T algorithm at time instant t_i is modeled as:

$$d(t_i)=d(t_{i-1})+\bar{v}_mT \quad (8)$$

Where, the term $\bar{v}_m$ represents the average measurement speed of the target node.

2.3. Cognitive Algorithm

The algorithm is described as follows:

Step 1 Initialization

Setting the values of T and A_{max} according to the different accurate positioning systems.

Step 2 Judging the motion state of target node

The value of Δd_{i+1} is calculated by the base station in (t_i,t_{i+1}). And the base station judges whether the target node is stationary according to $\Delta d_{i+1}=v_{mi}T<A_{max}$.

Step 3 Discarding the positioning data or not

1) If the target node is moving, the base station uploads the positioning data at the current time instant;

2) If the target node is stationary, the base station discards the positioning data at the current time instant.

Step 4 Showing the trajectory

If the control center receives the positioning data, the trajectory of the target node at the current time instant is displayed directly; otherwise, the control center uses the data predicted by V-T algorithm to replace the trajectory at the current time instant.

Step 5 Setting $i=i+1$, return to Step 2, until the target node leaves the coverage of the base station.

3. Simulation Analysis

The length of the underground coal mine roadway is usually hundreds of meters, and the width of the roadway is generally 3~6m. When the base station is in the central line of roadway, its vertical distance from the wall is 1.5~3m. The positioning accuracy of existing accurate positioning system is the order of meter, so relative to the length of roadway, the width of roadway can be ignored [13].

The simulation system consists of 20 target nodes, which are distributed randomly in a roadway of -150m to 150m. The base station is located at position (0). In this section, we present the simulations results for the algorithm. We perform simulation of the algorithm with MATLAB.

3.1. Simulation Parameters

In the coal mine, the speed of miner is mostly between 0~5m/s. So in this simulation, each node has the movement speed of 0~5m/s. The length of the positioning data is set to one packet, so the data generation rate of the target node equals 1/T packet/s. The details of the simulation parameters are shown in Table 1.

Table 1. Simulation Parameters

Parameter	Value
Terrain range	-150m~150m
Number of target nodes	20
Movement speed of target node	0~5m/s
Simulation time	3000s
System positioning accuracy	5m/10m
Positioning interval	2s/4s/6s/8s/10s

3.2. Simulation Results

Figure 2 shows the data flow reduced ratio of the system by cognitive algorithm when target nodes randomly move in the roadway. Simulation results show that when the system positioning accuracy is 5m, and the positioning interval is 10s, the cognitive algorithm can reduce 10% of the data flow; when the positioning interval is 2s,the cognitive algorithm can reduce 50% of the data flow. And when the system positioning accuracy is 10m, the cognitive algorithm can reduce 20%~70% of the data flow at different positioning interval.

It can be found that the cognitive algorithm can reduce the data flow of the positioning system. When the system positioning accuracy is lower or the positioning interval is shorter, the cognitive algorithm is more effective. In this condition, according to $v_m T > A_{max}$, the probability of target node in motion is smaller, then the cognitive algorithm can discard more positioning data, so the performance of data congestion control of the cognitive algorithm is more effective.

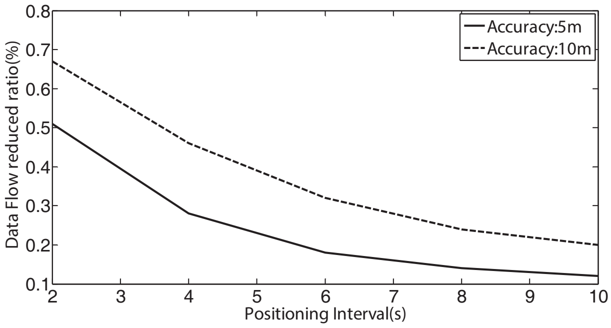

Figure 2. Data Flow reduced ratio of cognitive algorithm

Figure 3 shows the positioning accuracy reduced ratio of the system by cognitive algorithm when target nodes randomly move in the roadway.

Simulation results show that the cognitive algorithm will degrade the average positioning accuracy slightly. When the positioning interval is shortest, the average positioning accuracy degradation by the cognitive algorithm is less than 25%; and when the positioning interval is 10s, the average positioning accuracy degradation is less than 10%.

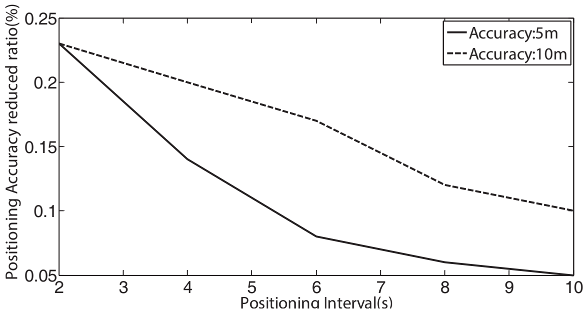

Figure 3. Positioning Accurate reduced ratio of cognitive algorithm

The cognitive algorithm by discarding the static data of the target nodes to control the data flow of the positioning system, and the control center uses V-T algorithm to predict the discarded data of the target nodes, and in order to compensate for the loss of the positioning accuracy. But when too many positioning data are discarded, the performance of V-T algorithm is degraded greatly, so the prediction accuracy of the discarded data is decreased. In this condition, the positioning accuracy is reduced obviously.

Figure 4 and Figure 5 show the trajectory tracking performance of the system by cognitive algorithm and non-cognitive algorithm when the system positioning accuracy is 10m.

Simulation results show the trajectories of the target node by cognitive algorithm are same with the trajectories by unused the cognitive algorithm roughly. Although this algorithm is slightly reduced positioning accuracy, the trajectory tracking performance of the system is not degraded.

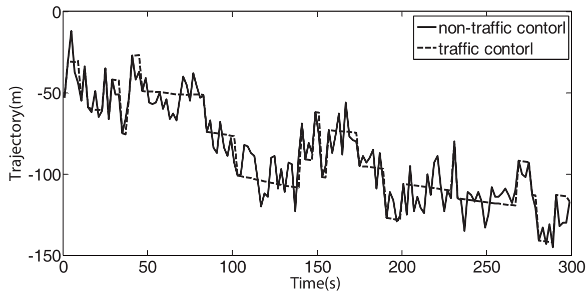

Figure 4. Comparison of trajectories of non-cognitive algorithm and cognitive algorithm at T=2s

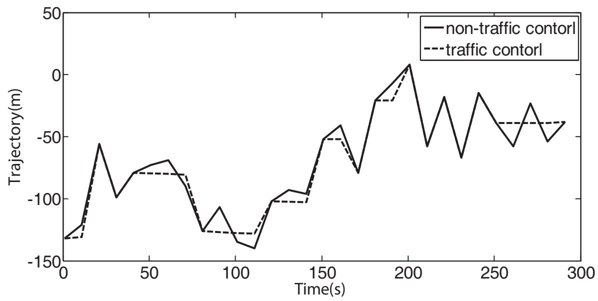

Figure 5. Comparison of trajectories of non-cognitive algorithm and cognitive algorithm at T=10s

Conclusions

In this work, we analyze the factors related with the data flow, and we have developed a cognitive algorithm base on congestion control for underground accurate positioning system. The cognitive algorithm perceives the motion states of target nodes, and discards a part of static positioning data to reduce the data flow to avoid network congestion. Simulation results show that the proposed algorithm can greatly reduce data flow of the accurate positioning system, and don't degrade the trajectory tracking performance.

Due to the range of the system positioning accuracy of underground accurate positioning system is 5m~10m, and the speed of the miners is slow, so the cognitive algorithm can be suitable for the coal mine.

Acknowledgments

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