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Green and Confident Group Detection in Vehicle Sensor Networks

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Abstract: Vehicle Sensor Networks (VSNs) are a new solution for road event detection with great advantages. Beyond this, green ICT (Information and communication Technology) is a new focus with the goal of saving energy and cut down carbon emissions. Green and Confident Group Detection (GCGD) scheme by using local dynamic cluster model is proposed to guarantee valid detection demand with good energy efficiency. The experiment results show that the model provides effective detection performance in terms of user demand and save energy consumptions.

Key words: Vehicle ad hoc networks, green ICT, road detection, energy efficiency, dynamic cluster

INTRODUCTION

Road detection is important to driving safety and ordered transportation. Participate sensing encourages people to take part in environment monitoring by smart devices they carry with. A vehicle sensor network is a kind of special mobile wireless sensor networks within vehicle environment (Lan *et al*., 2012). Sensor devices equipped on vehicles constitute a vehicle based mobile sensor network. Because of the mobility and coverage of vehicles in a city, a VSN provide a novel and convenient solution for road detection. For high mobility of vehicles, sensing data collected is often sparse according to time and space. Green ICT (Information and communication technology) is focused for reported high carbon emissions each year. In terms of the global carbon emissions, some analysts have reported that ICT accounts for 2-2.5% of all harmful emissions which is equal to the global aviation industry (Raju *et al*., 2013).

In this study, we consider the group detection problem in road detection using a VSN in terms of specific detection performance demand. Considering green ICT demand, we study optimal and efficient vehicular sensing and communications in road detection which could guarantee confident event detection performance.

The main contribution of this study includes (1) An event detection mechanism is proposed to guarantee required performance when making trade-off with energy consumptions, (2) The dynamic local cluster is invoked to make green and confident group detection and (3) Involve green ICT into road detection applications.

BACKGROUND AND RELATED WORK

VSNs could be used in a wide range of applications, e.g., used in traffic monitoring to save communication costs and avoid network congestions (Li *et al*., 2009).

In recent research work of sensor networks, road surface monitoring related applications are popular. Some researchers (Mohan *et al*., 2008) propose system solution to monitoring road and traffic conditions in a city which aims to detect potholes, bumps, braking and honking by using smart phones with the accelerometer, microphone, GSM radio and GPS sensors. Some researchers (Karuppuswamy *et al*., 2000) propose a vision-based scheme for pothole avoidance in a mobile robot by the use of cameras. They detect potholes by looking for large circular objects in the field of view. Some researchers (Eriksson *et al*., 2008) propose road surface pothole detection by using machine learning mechanism based on Hidden Markov Model.

Existing approaches for event detection in wireless networks could be approximately divided into three kinds of methods. The first kind of method is based on node sensing coverage (Zeng *et al*., 2010) which chooses at least k nodes awake and the other nodes in energy-saving sleep mode to guarantee detection coverage. The second kind of method utilizes machine learning which depends on event detection through local node collaboration. Some literatures propose to use machine learning to make future classification, use Hidden Markov model to decide event probability and hybrid ways. Some people (Singh *et al*., 2008) make research on relationship between

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high-level (synthesized) and low-level (observed) data by utilizing Hidden Markov Model based target tracking evaluation to reconstruct target position and trajectory. Some researchers (Keally *et al*., 2010) propose confident event detection algorithm based on Hidden Markov Model in terms of application-specific detection demand. The third method is based on application-specific and module-specific sensing methods (Isler and Bajcsy 2006), such as accelerator-oriented sensing model, camera-based target localization sensing model and mathematics-based probability noise distribution sensing model.

Green communication and computing have been proposed as a solution to addressing the growing cost and environmental impact of telecommunications. Some researchers (Sanctis *et al*., 2011) discuss several techniques on energy efficient wireless networks towards green communications.

SYSTEM MODELS

We try to construct dynamic vehicle clusters to guarantee confident road detection in terms of user specific detection accuracy. The dynamic cluster is structured through the use of Local Invoker, Cluster Generation and Runtime Decision Modules. The local invoker is the vehicle node that finds itself with sparse data. The local invoker will send out a GD-Req message to request group detection. The cluster generation process is to choose similar vehicle to take part in event detection and help to meet user required detection performance. The runtime decision modules will decide the vehicle to join into the group detection or not.

Assume that each node has two energy modules: working and energy-saving module. In energy-saving module, the node extends the sleep period in each duty cycle, i.e., it has a longer time to turn off its sensing and communication modules to save energy.

Each node could be in one of the states: observe, decide and adapt as shown in Fig. 1. "observe" is the initial state for vehicle nodes. In this state, the node will sleep and work periodically. If a node finds itself with sparse data and cannot provide required detection performance, it then becomes a local invoker. "decide" is the state when it receives a GD-Req message and then makes decision on cooperation. "adapt" is the state that decides on switching to energy-saving model or not according to cooperation or not. If a node is not invited into group detection (i.e., does not make cooperation), it switches into energy-saving module. Otherwise, the node will cooperate to make group detection and it keeps in working module.

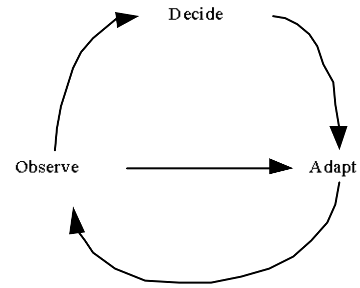

Fig. 1:Node states in green and confident group detection

GCGD DESIGN

Local invoker: If a vehicle that detects a specific road event cannot guarantee the user demanded performance, it becomes a local invoker. The local invoker will broadcasts a GD-Req to invoke cluster based group detection in the networks. The local GD-Req message broadcast is based on CSMA/CA mechanism to avoid contentions. The GD-Req message includes invoker ID, current vehicle ID/state and local event probability r_l. The node that receives a GD-Req message enters into "decide" state which makes decision on cooperation.

Algorithm 1 describes the local invoker selection. The ground truth is based on trace data collected through video recording or provided by an upper layer application.

```
Algorithm 1: Local invoker selection
Input: Set of all vehicle nodes in a VSN N, user-defined false positive rate
u.FP and negative rate u.FN, local observations O, ground truth G, initial
state observe
Output: Local Invoker nodes
for each node in N
 If (local event probability r_l>0) and (O.FP> u.FP) and (O.FN>u.FN) then
 broadcast a GD-Req message
        state_adapt(working)
 endif
 If receives a GD-Req message then
 state_decide
 endif
endfor
```

Cluster generation and runtime decision: In cluster generation, we invite useful vehicles that contribute to detection and try to improve detection capabilities. For those vehicles that cannot contribute event detection, they could be changed into energy-saving module to save energy.

We propose a metric called event detection relevance to determine useful vehicles. Assume vehicle i and j get observed data $O_l(i)$ and $O_l(j)$ within time duration l. For vehicle i and vehicle j, the detection relevance on event e donated as $co^e_l(i, j)$ which is defined as shown in Eq. 1. In which, is the event probability of vehicle i during time duration l and $r_{threshold}$ is threshold for detect an event:

$$co_l^e(i, j) = \| r_{e,t}(i) - r_{e,t}(j) \|,\ r_{e,t}(i), r_{e,t}(i) > r_{threshold} \quad (1)$$

If $\geq R_{threshold}$, it implies that vehicle i has similar event detection as vehicle j. $R_{threshold}$ is given and adapted by applications. The correlation between vehicles could be found out by the above method.

The group detection uses similar vehicles to improve detection performance. The similar vehicles join into the cluster until local detection performance is achieved.

Algorithm 2: Cluster generation and runtime decision

```
Input: Set of all vehicle nodes in a VSN N, user-defined false positive rate
u.FP and negative rate u.FN, local observations O, ground truth G, initial
state observe
Output: Set of clusters C = {Ci}
for each node j in N
 If (state = observe) and receives a GD-Req message then
 state_decide
 endif
If(state=decide) and (co^e_l(incoke_id, j)≥R_threshold) && (For_num
<MAX_FOR) then
        state_adapt(working)
        Update r_l, O.FP, O.FN.
        If(O.FP> u.FP) &&(O.FN> u.FN) then
 forward a GD-Req message
else
 state _adapt(energy-saving)
endif
endif
endfor
```

Algorithm 2 describes cluster generation and runtime decision. After the invoker broadcasts out a GD-Req, the neighbors receives the message will decide whether to join the group detection or not by event detection relevance. The similar vehicle is involved into the detection to improve performance. The GD-Req will be forwarded in the network until achieves confident event detection. Among the process, similar vehicles are chosen to cooperate into group detection by entering into "adapt" state and choose "working" energy module. The other less relevant vehicles enter into "adapt" state and choose "energy-saving" energy module. To curb the number and scale of forwarding messages, a maximal forward number MAX_FOR is defined to avoid excessive broadcast messages in the network.

Each node cooperate in the group detection will stay in working module until the end of the event, i.e., $r_l < r_{threshold}$. Then the node will change back to "observe" state and broadcast out an AWAKE message. The nodes in energy-saving module receives the message during its short listening period will change back to "observe" state.

EXPERIMENTS

We use a simulated testbed that consists of 5 remote controllable vehicles. The vehicle could travel with speed from 0 to maximal 0.48 m sec^{-1}. It can work over 30 min continuously in the testbed. There are bi-directional outside/inside lanes for control driving. There are several artificial upward/downward slopes built in the test place to simulate complex road driving. Each vehicle is placed randomly on different locations and lanes and then controlled to drive in different directions around the test area. The artificial experiment scenarios are used to simulate uneven, wet and slippery road conditions. The sensors used in our experiments include 3-axis high-sensitivity accelerometers.

Figure 2 shows the detection accuracy within different scenarios. The results show we get better accuracy when using group detection. GCGD helps to improve the accuracy of detection. Figure 3 shows false

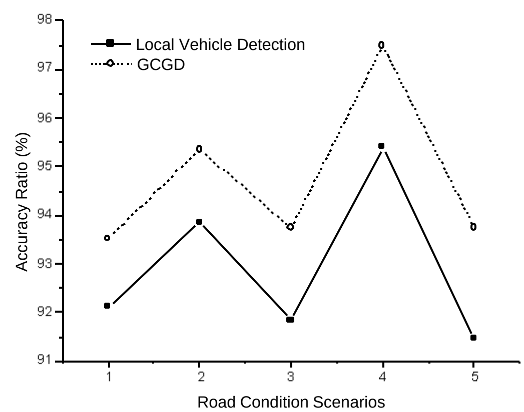

Fig. 2: Detection accuracy ratio

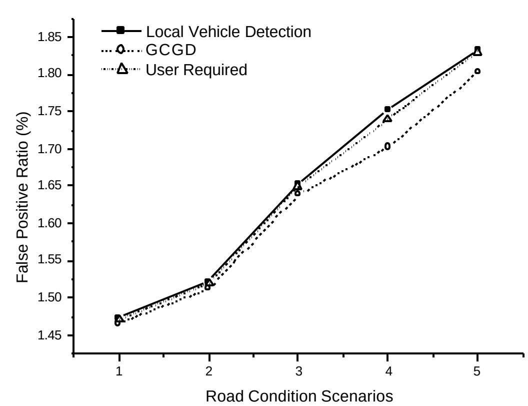

Fig. 3: False positive ratio within different scenarios

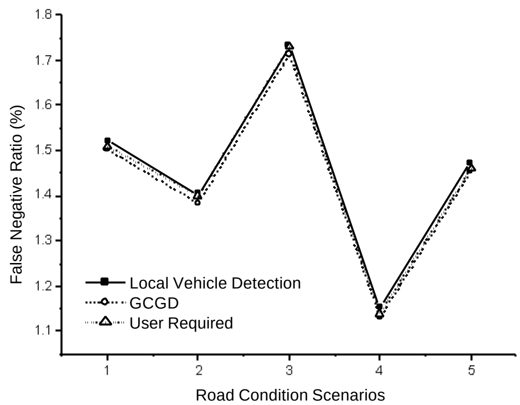

Fig. 4: False negative ratio within different scenarios

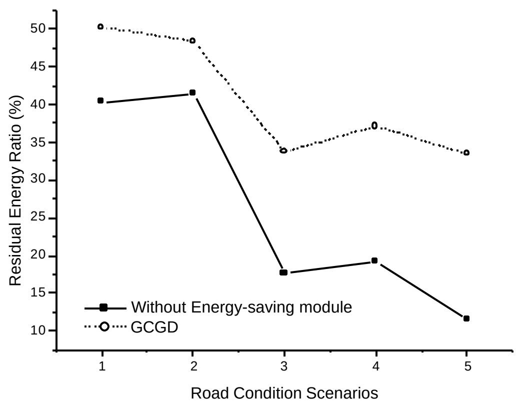

Fig. 5: Residual energy ratio within different scenarios

positive rate within different scenarios. GCGD helps to improve the false positive rate and achieves confident detection. Figure 4 shows the false negative rate within different scenarios. Figure 5 shows the residual energy ratio within different scenarios. The residual energy ratio is calculated by residual energy versus initial energy.

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CONCLUSION

Vehicle sensor networks are utilized in Intelligent Transportation Systems nowadays which can be used to inform the drivers about many kinds of road condition events. By the way, vehicles incur carbon emissions and have impact on environment. In this study, we propose green and confident road detection called GCGD in VSNs. GCGD design makes tradeoff between detection performance and energy consumption. The experiments are carried on 5 controllable vehicles by simulating transportation scenarios. The results show GCGD can help to improve detection performance in terms of user demand and also save energy effectively.

The further experiments will also be carried on testbed consisting of voluntary cars equipped with sensors on real road areas. The test results will also be compared with other related work to testify the effectiveness.

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