Barrier-coverage for City Block Monitoring in Bandwidth Sensitive Vehicular Adhoc Networks

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***Abstract*—Recently, vehicular ad hoc network (VANET) is receiving lots of attentions as this new networking technology is expected to improve our daily driving experience greatly and will enable a number of emerging applications. It is envisioned that the vehicles in VANETs are armed with a number of advanced technologies such as wireless transceiver, video cameras, etc. This paper investigates the potential of the advanced VANET nodes to construct an impromptu surveillance system to surround an area of interest, which can be a city block, such that any suspect of interest leaving the city block can be monitored by a VANET node participating the surveillance system. Such a system can be useful to provide an emergency response system to keep the track of suspects who are leaving the area by walk or by car after committing a crime inside the block, e.g. Boston bombing suspects. We observe that as the network bandwidth is limited, not all vehicles can participate and transmit video to the control center in real time. Therefore, we propose new scheduling algorithms for the VANET nodes, which consider the mobility of each vehicle as well as the network bandwidth and continuously provides barrier-coverage circumventing the city block over a given mission period. Via simulation, we show the efficiency of our algorithms.**

I. Introduction

Nowadays, vehicular ad-hoc networks (VANETs) are attracting lots of attentions as a key enabler of various emerging applications such as public safety, traffic management, policing and enforcement, pricing and payment, and surveillance. Currently, a number of major vendors, such as Audi, Ford, GM, Toyota and Mercedes-Benz, are developing an early collision warning system using VANETs. In addition, the researchers at Carnegie Mellon University, Rutgers University, and University of Carolina, Berkeley are collaborating to build a road traffic control and information system by exploiting the information collected from VANETs [1]. Thanks to those continuing efforts, it is envisioned that in the near future, VANET nodes are expected to be well-armed with a number of state-of-art technologies such as wireless transceivers for long distance communications, cameras to record important events and analyze surrounding situation, etc.

Over the past years, a number of VANET applications have been emerged in the literature. Among those, the surveillance capability of VANET nodes have been actively discussed as several key components for this application including wireless transceiver and video camera are readily available for many VANET nodes. For instance, Gerla et. al. [2] introduced a new framework to collect pictures from VANET nodes. In [3], Hussain et. al. studied the privacy and security of a VANET application where selected VANET nodes upload live video to a Cloud provider for later use.

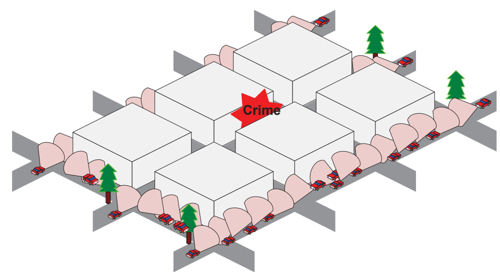


Fig. 1: An illustration of barrier coverage to circumvent a block of interest using VANET nodes.

In the traditional wireless sensor networks (WSNs) and wireless video sensor networks (WVSNs), a group of sensor nodes are told to provide a “barrier-coverage” over an area of interest if the sensor network can always detect an intruder of interest who trespasses the area from outside. The WSN can provide the barrier-coverage if the sensor nodes in the WSN can form a seamless line of sensors surrounding the area of interest. To the best of our knowledge, the construction of barrier-coverage has been discussed in the context of static WSNs so far. In this paper, we introduce a new problem of how to constantly provide barrier-coverage for region of interest (ROI) over time, specifically speaking a city block, using VANET nodes which are equipped with wireless transceiver and camera sensors in bandwidth limited VANET environment (see Fig. 1).

In essence, VANET is a dynamic network as all of VANET nodes are expected to have high level of mobility compared to the static nodes in WSNs. Furthermore, it is expected that the VANET infrastructure, especially the road side units (RSUs), which are relay nodes between VANET nodes and the rest, can support the real time video transmission to the central authority from only a limited number of VANET nodes. As a result, we have to design a scheduling algorithm to minimize the number of VANET nodes which can transmit a message to a RSU concurrently. In addition, a data aggregation strategy is considered for the selected VANET nodes so that the city block of our interest can be seamlessly surrounded by the VANET nodes during the mission period without causing an excessive multimedia traffic at a RSU.

Contributions of This Paper. The main contribution of this paper has two folds.

(a) We introduce a new barrier coverage problem in VANETs, whose goal is to find the minimum number of VANET nodes for each unit time so that the block of interest can be seamlessly circumvented during the mission period. We consider this problem in the context of VANET nodes which are equipped with camera sensors with both fixed direction and adjustable direction, and propose a **polynomial time exact algorithm** for both cases. To the best of our knowledge, this is the first work to discuss the need of VANET barrier coverage.

(b) After selecting the minimum number of vehicular cameras to form a barrier, it is still possible that an excessive number of VANET nodes which transmit video data to the central authority at the same time and cause more wireless traffic than nearby wireless infrastructure can handle. To resolve this issue, we construct a data aggregation tree to reduce the amount of the packets toward a RSU.

The rest of paper is organized as follows: Section 2 gives a brief discussion about VANET Applications and barrier coverage in WSNs and WVSNs. In Section 3, we present network model and problem formulation about barrier coverage for city block monitoring. Section 4 is devoted to present an algorithm to construct barrier coverage using the minimum number of static or adjustable vehicular cameras in order to consider network bandwidth limitation and mobility in VANETs. Section 5 describes simulation results and corresponding analysis. Finally, we conclude this paper in Section 6.

II. Related work

A. VANET Applications

In VANETs, we can make two categories: safety related topics and internet connectivity related topics. For safety related topics, several applications have been introduced using Intelligent Transportation System. In [4], the authors describe road traffic information system based on vehicle to infrastructure (V2I). This road traffic control system can collect traffic information from individual car and disseminates the traffic information as signaling neighboring nodes to reduce traffic congestion. In [5], the author describes a live video streaming service in VANETs and proposes architecture to provide a streaming service. In [6], the author discusses about transmitting a large amount of data in V2I or vehicle to vehicle(V2V) communication and propose a solution based on idea of BitTorrent application for peer to peer networking. In [7], the author describes how to support robust video communication across multi-hop networks between vehicles in the emergency situation. In [8], the author describes fast triggering method. This scheme is able to bring triggering message to destination in a reduced number of hops for multi-hop message delivery. In [9], the author studies and propose a solution to support video streaming services using license-free wireless communications between vehicles and RSU in the high mobility and dynamic topology of VANETs. In [10], the author proposes a new analytic mobility model based on queuing network model to represent and model mobility pattern of vehicle in dense or sparse scenario.

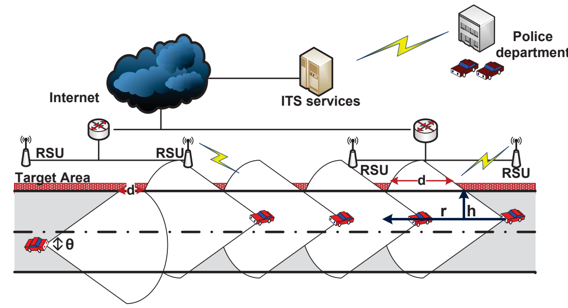


Fig. 2: Network model for barrier coverage in VANETs

B. Barrier Coverage in WSNs and WVSNs

In wireless sensor network the concept of barrier coverage introduced first in the Command control for many-robot systems. In [11] and [12], the authors propose efficient algorithm whether a region achieve k-barrier coverage using belt region in wireless sensor network and derive the critical condition of weak barrier coverage when sensor nodes are deployed randomly. In [13], the author studies that different deployment strategy affects barrier coverage on wireless sensor network and suggest that the sensor deployment strategy and planing have to be carefully examined. The critical condition of strong barrier coverage problem is derived in the [14] and the paper proposes algorithm to construct disjoint barriers in a large sensor network. The existing work considers a scalar sensor in barrier coverage. But, as camera sensor has different angle that is not omni-directional view, many researchers have considered specific angle. In [15], the author proposes a distributed algorithm to achieve barrier coverage on wireless camera sensor networks. In [16], the author proposes a new method to select camera sensor to make barrier coverage and reduction method to effectively reduce the number of cameras used. In [17], the author studies how to efficiently achieve barrier coverage in hybrid directional sensor network with stationary and mobile sensor nodes and proved the minimum number of mobile sensors required to form a barrier. In [18], the author studies a novel model to be full-view covered of object from 0 to 2π considering face direction in camera sensor networks and proposes an efficient model for full-view coverage detection and derive a necessary and sufficient condition on the sensor density for full-view coverage in the random uniform deployment. In WVSNs, [19] study the breadth, which is the width of image that a camera sensor can capture, to increase the quality of monitor(QoM) and propose β-breadth belt-barrier construction algorithm without rotation and the enhanced distributed β-breadth belt-barrier construction algorithm with rotation. In [20], the author proposed the k concurrent β-breadth belt-barrier construction problem to improve the fault-tolerance assuming that sensor nodes are likely to be faulty. In this paper our work is first to study barrier coverage problem with hybrid camera for vehicular ad-hoc networks.

III. Network Model and Problem Formulation

In this section, we describe our network model, notation and problem formulation.

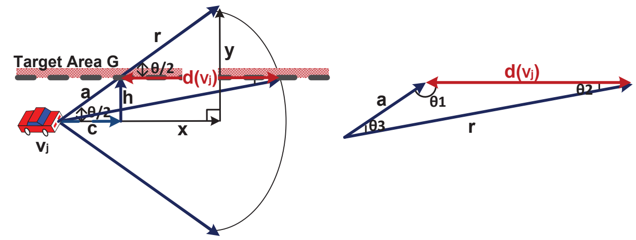
A. Network Model

We assume each VANET node is with a camera sensor and an on-board unit (OBU), which is armed with various state-of-art components including wireless transceiver, a GPS device, as well as a processing unit. Each node is able to transmit a real-time video stream from its onboard camera once it is within the communication range of a RSU [21]. We assume that each RSU is capable of relaying real-time videos from at most q VANET nodes at the same time. We also assume the upload link from each VANET node to a RSU requires the minimum network bandwidth τ to make the communication successful. Once an urgent event of interest occurs, we assume each VANET node reports its travel plan (its location per each second) for next 10 seconds per every 5 seconds so that the central control center can produce a schedule, i.e. who needs to upload real-time video to which RSU. Specifically, the police department gets the information and the control of each vehicle through the following procedure in Fig. 2:

(a) The police agent broadcast a location request message through the intelligent transportation systems (ITS).
(b) Each vehicle responses theirs information through ITS: { ID, Time Stamp, Location, Velocity, Direction, Camera Direction }
(c) The police agent broadcast monitoring schedule time in emergency situation through ITS. { ID, Time Stamp, Location, Camera On/Off, Camera Direction }
(d) Each vehicle reports monitored information based on monitoring time schedule to ITS. { ID, Time Stamp, Location, Sensing Data }

B. Notation and Problem Statement

Suppose there is a set V of n vehicles $\{v_1, v_2, v_3, \cdots, v_n\}$ nearby the block B of our interest. In reality, this set can be constructed by selecting a set of VANET nodes which can get the area nearby the block B within the next 10 seconds and this can be determined based on their reported speed and direction. For the sake of simplicity of our discussion, we assume B is a rectangular-shaped region and can be divided into equal-sized regular rectangles $\{g_1, g_2, g_3, \cdots, g_l\}$. During the rest of this paper, we use G to refer this set, and will name this set by a "target set" as well as each element in the target set simply by a "target area". We assume the VANET nodes are homogeneous, i.e. with the equivalent hardware, and further assume the sensing range of each camera is r and its field-of-view is FoV_{f_i}. We use $L(X_i, Y_i)$ to notate the geographical coordination of a node v_i on the 2-dimensional space which can be measured by the onboard GPS unit. We also use $L'(x_i^{ul}, y_i^{ul}, x_i^{rb}, y_i^{rb})$ to represent the geographical location of s_i, where (x_i^{ul}, y_i^{ul}) is the left-top coordinate of s_i and (x_i^{rb}, y_i^{rb}) is the right-bottom coordinate of s_i. Time slot



(a) (b)

Fig. 3: Coverage distance in VANET

T = $\{t_1, t_2, t_3, \cdots, t_m\}$ means time duration in which target region is monitored or surrounded by each vehicular camera.

Definition 1 (Camera Coverage Distance)**.** *Given a target area G and a VANET node v_j whose (camera) sector-shaped coverage area, the camera coverage distance of v_j is the border line of G which is visible from v_j. In other words, it is the distance of overlapped region between G and the sector-shaped coverage area in the geometry, e.g. $d(v_j)$ in Fig. 3(a) and Fig. 3(b).*

Definition 2 (Barrier Path)**.** *Given a block B of interest and a set V of VANET nodes, a barrier path BP consists of a set of camera coverage distances provided by V such that the union of them can seamlessly surround B.*

It is clearly, at any moment, if a given set V of VANET nodes can provide a barrier path surrounding B, then the VANET provides barrier-coverage over B.

Problem 1. *Given a set of n vehicles $V = \{v_1, v_2, v_3, \cdots, v_n\}$,which is installed directional camera, on the road we want to choose the minimum number of vehicular sets required to form barrier coverage over target region in order to consider network bandwidth limitation.*

Problem 2. *Given a set of barrier coverage set $C = \{c_1, c_2, c_3, \cdots, c_k\}$ we want to construct fault tolerant data aggregation tree in highly dynamic topology scenario due to high mobility nature of VANET node.*

IV. Barrier Coverage Algorithm with Camera for VANETs

In this section, we present an algorithm to find the minimum number of vehicle sets required to form barrier coverage with static and adjustable cameras for VANETs.

A. Coverage distance calculation

We assume that we know vehicular location by GPS device and target area by map information. As given camera field-of-view (FoV_{f_i}), camera sensing range (r) and the distance (h) between target areas $L'(x_i^{ul}, y_i^{ul}, x_i^{rb}, y_i^{rb})$ and vehicle location $L(X_i, Y_i)$, we can calculate x and y using cosine equation $(cos\frac{\theta}{2} = \frac{r}{x})$ and Pythagorean theorem $(r^2 = x^2 + y^2)$. The c value can be calculated as the ratio is h:y = c:x. After that we can get the coverage distance using the following law of sine equation $\frac{r}{sin\theta_1} = \frac{a}{sin\theta_2}$ and $\frac{D}{sin\theta_3} = \frac{r}{sin\theta_1}$ in the Fig. $3(b)$. In order to calculate coverage distance of each vehicle, we use the following algorithm.

Algorithm 1 Coverage Distance for VANETs

Input: vehicular location $L(X_i, Y_i)$, target location $L'(x_i^{ul}, y_i^{ul}, x_i^{rb}, y_i^{rb})$
Output: a set of coverage distances D

h = Y_i - y_i^{rb};
r = sensing range;
θ = beam width;
n = the number of vehicles;
for $i \in 1..n$ **do**
  $x = rcos(\theta/2)$
  $y = \sqrt{r^2 - x^2}$
  $c = \frac{(hx)}{y}$
  $a = \sqrt{h^2 + c^2}$
  $sin\theta_2 = a \times \frac{sin(180-(\theta/2))}{r}$
  $d_i = \frac{r}{sin\theta_1} \times sin\theta_3$
end for

B. Barrier Coverage with static vehicular camera

We have the set of coverage distance calculated by an algorithm 1. In order to find the optimal barrier coverage in the set of coverage distance we can convert this problem to the following shortest path problem. The technique to find the minimum nodes using s-t path have been used in the [22],[23]. The each coverage distance has the concrete target coverage position such as start point $d_s(i)$ and end point $d_f(i)$. We describe how to convert from this problem to shortest path problem.

1) Step 1: Graph transformation: If $d_s(j) \leq d_f(i)$ and $d_f(i) < d_f(j)$, the connected path exists between d_i and d_j. In other words, if the coverage distance overlap between d_i and d_j, the connected edge exists between two nodes(i, j). By graph transformation we can construct weighted directed graph by adding virtual node S and T which is start node and terminal node. If the edge exists between node S and the other node, the edge weight is the defined min coverage weight(α). If the connected edge exists between two nodes except for S, the edge weight is calculated by $w(v_i, v_j) = Max\ Coverage\ Weight(MCW) - d_w(v_i)$. The edge weight of node is represented by coverage distance value as follows:

$$w(v_i, v_j) = \begin{cases} MCW - d_w(v_i) & if\ v_i, v_j \in overlap \\ \alpha & if\ v_i\ is\ S \\ \infty & otherwise \end{cases}$$

2) Step 2: Shortest path finder: The set of coverage distances $D = \{d_1, d_2, d_3, \cdots, d_n\}$ calculated by the location of each vehicular camera in the Fig. 4(b) is transformed the weighted directed graph as shown in Fig. 5. As we find shortest path using modified Dijkstra algorithm from transformed weighted directed graph, we can turn off redundant VANET node which increases network usage when barrier coverage is formed.

Fig. 4(a) shows target area to monitor critical region and crossing path where crime suspect can escape. Fig. 4(b) shows only bottom line in the Fig. 4(a) for simplicity. It shows a

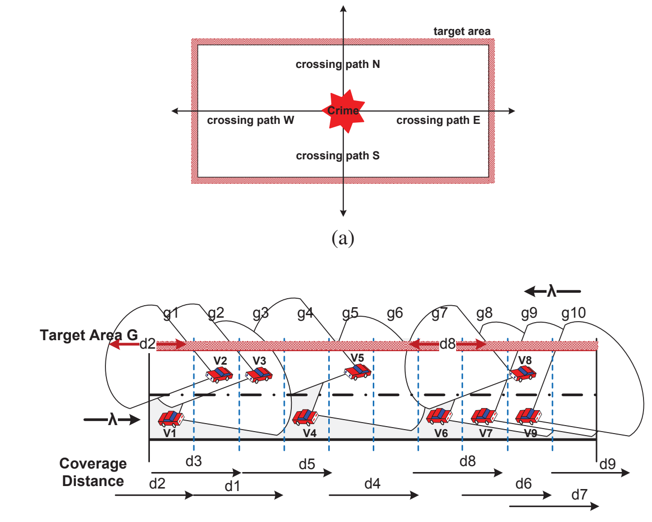


Fig. 4: Barrier coverage with static vehicular camera

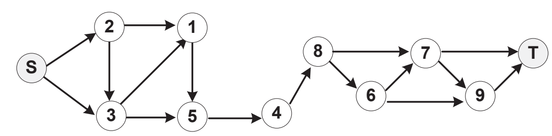


Fig. 5: Directed weighted graph from coverage distance with static vehicular camera

scenario with 9 cars with static camera and 10 consecutive target areas. As each vehicular camera has a coverage distance calculated by algorithm 1, v_1 has a coverage distance d_1 based on target area which can detect or monitor. v_2 has a coverage distance d_2. v_3 has a coverage distance d_3 and so on. Therefore, the set of coverage distances is $D = \{d_1, d_2, d_3, \cdots, d_9\}$. These coverage distances is transformed a weighted directed graph as shown in Fig. 5 by *Step 1: Graph transformation*. If both coverage distance d_1 and d_2 overlap to each other, two vertexes has connected edge otherwise no edge exists. If the connected edge exists, the edge weight is calculated by $w(v_i, v_j) = MCW - d_w(v_i)$. After graph transformation, the virtual node S and T are added in this graph. If node S is connected to the other node, the edge weight has the min coverage weight(α). In this example, we can find the minimum number of sets $\{d_3, d_5, d_4, d_8, d_7\}$ to form barrier coverage using modified shortest path algorithm. As the set of these coverage distances $\{d_1, d_2, d_6, d_9\}$ overlap with the other coverage distance, this set of coverage distance is redundant set caused by network disability incurring network burst during certain time.

Theorem 1. *if a path exists between S and T in the graph, the barrier coverage also exists.*

Proof: Proof by contradiction. Assume that the barrier coverage does not exist when a path exists between S and T. If $d_s(i) < d_s(j)$ and $d_s(j) \leq d_f(j)$, the path exists between d_i and d_j. As d_i and d_j overlap, in other words, the edge exists between d_i and d_j . Considering coverage distances d_i in the set of barrier coverage (C^*), the starting node is S. S

and d_1 has a connected path and this means that S and d_1 overlap. When d_1 and d_{1+i} have a connected path, the overlap exists between d_1 and d_{1+i}. In the same way, the overlap exists between d_{i+1} and T when there is a path between them. Finally, if we have a connected path between S and T, these nodes overlap to each other continually. In other words, it has barrier coverage in the graph. This assumption is contradict. ■

We proved Theorem 1 by contradiction that if we find a connected path between S and T in the transformed weighted directed graph, the barrier coverage can be constructed.

C. Barrier Coverage with adjustable vehicular camera

Unlike static vehicular camera, adjustable vehicular camera has a pan-tilt-zoom (PTZ) function to provide the best possible field-of-view (FoV) [24] [25]. Fig. 6(a) shows that the change of camera direction by PTZ function represents a different field-of-view (FoV) of camera. This changed FoV covers a different target areas. Therefore this adjustable vehicular camera has a various coverage distance based on different FoV. In this problem, for simplicity, we assume each vehicular camera has three fixed camera directions and weight (eg, $0°, 22.5°, 45°$). In Fig. 6(a), F1 represents FoV_{f_1} by original camera direction which is unchanged by 0°. F2 represent different FoV_{f_2} by the changed camera direction which is moved in clockwise by 22.5°. Therefore the vehicular V_2 in Fig. 6(b) has three different coverage distances such as $d_{2_1}, d_{2_2}, d_{2_3}$ by three different field-of-views (eg, $FoV_{f_1}, FoV_{f_2}, FoV_{f_3}$). These three different coverage distances have three different weights. Like vehicle with static camera, we can get the set of coverage distances calculated by algorithm 1.

Algorithm 2 Barrier Coverage Algorithm for VANETs

```
Input: a set of coverage distances D, time duration [T1, T2]
Output: a set of barrier coverage C*
while t ≤ T2 do
    C* = {∅};
    X* = {∅};   // a set of connected edges X*
    Sort D according to ds(i) in this ascending order;
    for i ∈ 1..n do
        for j ∈ i..n do
            if overlap between di and dj then
                Add eij to X*;
            end if
        end for
    end for
    Construct the weighted directed graph from X*;
    C* = find shortest path using modified Dijkstra's algorithm;
    if totalWeight < τ then
        return C*;
    else
        return {∅} ;
    end if
    t = t + 1;
end while
```

This set of coverage distances is transformed to the weighted directed graph in Fig. 7 by *Step 1: Graph transformation*. In this transformed weighted directed graph even though the overlap point exist in the set of coverage distance, it has no connected edge in the following case: 1) two congruent coverage distances of different vehicular camera, 2) three different coverage distances by different direction of same vehicular camera.

After graph transformation, the mathematical formulation to find shortest path is as follows:

$$\min \sum_{(i_j,k_l)\in E} w_{(i_j,k_l)} x_{(i_j,k_l)} \tag{1}$$

subject to

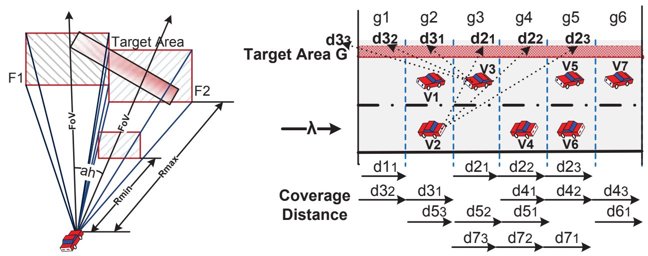
$$\sum_{k_l\in E}^{N} x_{(i_j,k_l)} - \sum_{m_n\in E}^{N} x_{(m_n,i_j)} = b_{i_j} \quad (\forall i_j) \tag{2}$$

$$x_{(i_j,k_l)} \geq 0 \quad (\forall i_j, k_l) \tag{3}$$

$$\sum_{(_j,k_l)\in E}^{N} x_{(i_j,k_l)} \leq 1 \quad (\forall i) \tag{4}$$

In the above linear programming model, the objective is to minimize the total cost of path. The first constraint restricts that incoming flow and outgoing flow are 0 except source node S and terminal node T. The second constraint restricts non negative value. The last constraint restricts choosing only one coverage distance among three different coverage distances of the same vehicular camera.

Fig. 6(b) shows small example comprised of a scenario with 7 cars with adjustable camera and 6 consecutive targets. Fig. 6(b) also represents subsection(bottom line) of the whole city block like in the Fig. 4(a). Each vehicle with adjustable camera has three coverage distances by three different FoVs. The v_1 has a coverage distance d_{1_1} based on the target area which can cover or monitor. The v_2 has three different coverage distances $d_{2_1}, d_{2_2}, d_{2_3}$. The v_3 has also three different coverage distances $d_{3_1}, d_{3_2}, d_{3_3}$ and so on. Therefore the set of coverage distances is $D = \{d_{1_1}, d_{2_1}, d_{2_2}, d_{2_3}, \cdots, d_{7_1}, d_{7_2}, d_{7_3}\}$. Every time each car has three different coverage distances by three different camera directions. These set of coverage distances can be transformed to a weighted directed graph as shown in Fig. 7 by *Step 1: Graph transformation*. If both coverage distances d_{1_1} and d_{3_1} overlap each other, two nodes has a connected edge otherwise they are not connected. Even though it has the overlap point between end point $d_f(3_1)$ and start point $d_s(3_2)$, it has no connected edge because of a different coverage distance by the same vehicular camera. In other words, at each time each vehicular camera can choose only one camera direction. If the edge exists as the coverage distance of two vehicular cameras overlap, the edge weight is calculated by $w(v_{i_j}, v_{k_l}) = MCW - d_w(v_{i_j})$. The virtual node S, which has the min coverage weight α, and T are added in this graph after graph transformation. And at each time each vehicle can choose only one direction. This means that the coverage distance of a vehicular camera have to choose only one in the several coverage distance list by camera direction. Therefore, The Equation (4) in the linear programming model restricts that one vehicular



(a) (b)

Fig. 6: Barrier coverage with adjustable vehicular camera

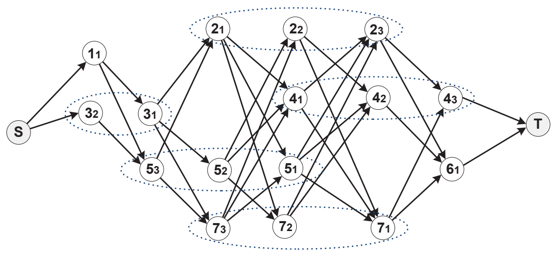


Fig. 7: Directed weighted graph from coverage distance with adjustable vehicular camera

camera selects one coverage distance. In this scenario, we can find the minimum number of vehicular cameras such as $\{d_{1_1}, d_{3_1}, d_{2_1}, d_{4_1}, d_{7_1}, d_{6_1}\}$, $\{d_{3_2}, d_{5_3}, d_{2_1}, d_{7_2}, d_{4_2}, d_{6_1}\}$, $\{d_{1_1}, d_{3_1}, d_{5_2}, d_{4_1}, d_{2_3}, d_{6_1}\}$ using the mathematical formulation.

D. Data aggregation scheduling in order to consider network bandwidth limitation

The data aggregation scheduling algorithm in order to consider network bandwidth limitation is important to reduce packet header overhead and wireless transmission collision which is caused by critical network failure. For example, if we assume that each vehicle uploads monitored data based on construction schedule (n vehicles) to form the required barrier coverage, the number of uploaded messages to ITS is n messages. If we use a data aggregation method, we can decrease it from n to $n/(2^{k\ level})$ forming clusters by distributed data aggregation tree method. The size of each cluster is $(2^{k\ level})$. So we represent a data aggregation algorithm in this section. We assume that the communication range is grater than camera sensing range and the tree level is three levels as a lager level may further increase the complexity and data delay of the system. As the sensing range is lesser than communication range, every node can communicate to each other forming barrier coverage. We construct data aggregation tree using existing method [26]. Each level has different colors like black for the first level, red for the second level and green for the third level. The ITS chooses a root vehicle at each cluster dividing section after finding the minimum number of vehicular cameras to form barrier coverage. The algorithm process is the following; Every vehicle is colored in white when vehicle didn't join data aggregation tree. The chosen root vehicle changes its color to black and sends colored-token message to neighbor nodes. When the neighbor nodes receive colored-token message from the black node, they change their colors to red if their colors are white. If the neighbor node is not in white color, the neighbor node compares node levels. In case the neighbor node receives a message from the higher level node, the neighbor node change the higher color(higher level) and joins that group. If the sender don't receive any reply message from neighbor nodes, this construction process of data aggregation tree stops.

Algorithm 3 Data Aggregation Tree Construction for VANETs

Input: a set of barrier coverage C^*, total number of required vehicles N_c
Output: data aggregation tree T

```
τ = BandwidthThreshold;
β = N_c / 2^(k level);
make Clusters as C* divided by β;
Choose root vehicle at each Cluster;
Root vehicle send Colored Token;
if Receive "Token" then
    if Vehicle == WhiteColor then
        Change Color from White;
        Reply JoinMessage;
        Broadcast Token;
    else
        if Color of vehicle ≥ Token then
            Discard Token;
        else
            Change Color from Token;
            Reply JoinMessage;
            Broadcast Token;
        end if
    end if
end if
Return data aggregation tree T;
```

V. Simulation Result and Discussion

In this section, we present the simulation result to evaluate our algorithm. We compare the number of static and adjustable camera of needed vehicles for barrier coverage.

A. Simulation Environment

To evaluate our algorithm, we simulate two types of programs: a static camera and adjustable camera using the modified Dijkstra algorithm and linear programming. We consider the three primary parameters: a) the minimum number of vehicular cameras required to form barrier coverage b) the minimum number of vehicular cameras required to form barrier coverage by arrival rate (λ) c) the probability to form barrier coverage by arrival rate (λ). Each result shown here is the statistical average of 100 simulations. The simulation was implemented in Java. In the simulation, vehicles are randomly distributed over a belt region of width from $L = 500m$ to $2000m$ and height $H = 8m$ (2 lanes). These values set as we assume a road with bi-direction and each direction has one lane in a city.

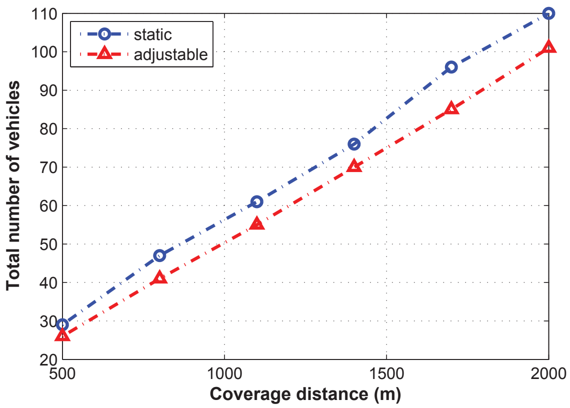


Fig. 8: The minimum number of vehicular cameras required by coverage distance

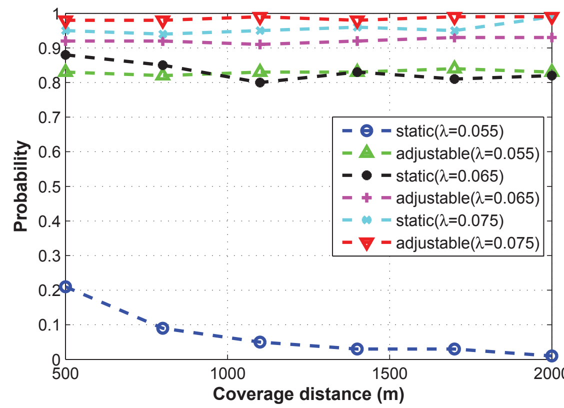


Fig. 10: Coverage probability by vehicular arrival rate

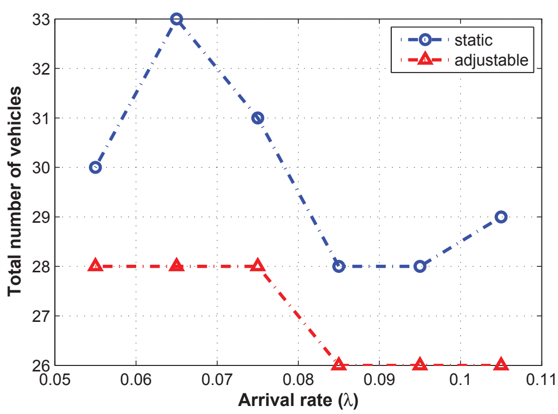


Fig. 9: The minimum number of vehicular cameras required by arrival rate

B. Simulation Results

We simulated three test cases: the required minimum number of vehicular cameras to form barrier coverage, how to affect the required minimum number of vehicular cameras by arrival rate and the probability to form barrier coverage by arrival rate.

Fig. 8 shows the difference in the minimum number of vehicular cameras required for barrier coverage between static and adjustable vehicular camera. It can be observed that the less number of vehicles required to form barrier coverage in the adjustable camera as expected.

We compare the minimum number of vehicular cameras required by arrival rate (λ) per meter in the region of $L = 500m$ and $H = 8m$. There is a small reduction of the minimum number of vehicular cameras required for barrier coverage after $\lambda = 0.08$ in Fig. 9. This is because we can choose more optimal coverage in the number of enough coverage list of vehicle after $\lambda = 0.08$. The result for adjustable camera is stable compared with one for static camera. And the Fig. 9 also shows that less number of cameras are required when adjustable camera is used.

We simulated how the probability to form barrier coverage change as the number of deployed vehicles increase. As each experiment runs 100 times, we calculate the coverage probability as counting the number of times when the desired coverage is achieved. In the Fig. 10, the result shows that the probability to form barrier coverage is over the 90 % if arrival rate is more than $\lambda = 0.075$ in the static and adjustable vehicular camera. When arrival rate $\lambda = 0.055$, the probability to form barrier coverage of static vehicular camera is very low compared with adjustable vehicular camera. However it shows that the adjustable vehicular camera achieves high possibility to form barrier coverage in case of low arrival rate. As we can see in the result if the optimization to decrease the number of vehicular camera using shortest path algorithm is not used, the number of vehicular camera for barrier coverage is increased as the total number of deployed vehicle increases. This situation causes the occurrence of network disability because the total size of vehicular camera data is over the network bandwidth (τ). As the redundant vehicular cameras for barrier coverage on the road are turned off through the redundancy reduction procedure using the proposed algorithm, the total amount of network bandwidth to use for monitoring ROI can decrease.

VI. Conclusion

In this paper, we describe and evaluate new method to form barrier coverage over VANETs. The camera barrier coverage problem is applied for VANETs in more practical way. We proposed an algorithm to find the minimum number of vehicular cameras to construct barrier coverage in moving vehicles with static and adjustable cameras in order to consider network bandwidth limitation for VANETs. Even after we find the minimum number of vehicular cameras to construct barrier coverage for VANETs, there can be possible still an excessive number of nodes which transmit video data to the central authority at the same time and cause more wireless traffic than nearby wireless infrastructure can handle. To overcome such situation, we also proposed an algorithm to form data aggregation tree to reduce packet overhead considering network bandwidth limitation. By using the simulation implemented in Java, we evaluated the performance of proposed algorithms. To the best of our knowledge, this is the first work to study barrier coverage problem with static and adjustable cameras in

VANETs. Overall, this proposed new application is expecting to be promising and practical solution for surveillance and reconnaissance operations over VANETs.

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