COMMUNICATION PROTOCOLS IN FRIEND: A CYBER-PHYSICAL SYSTEM FOR TRAFFIC FLOW RELATED INFORMATION AGGREGATION AND DISSEMINATION

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Abstract—In this paper, we explain in depth the communication protocols between different components of FRIEND: a cyber-physical system for traffic Flow-Related Information aggrEgatioN and Dissemination. Recall that FRIEND (which has been introduced in pervious work, by integrating resources and capabilities at the nexus between the cyber and physical worlds, FRIEND will contribute to aggregating traffic flow data collected by the huge fleet of vehicles on our roads into a comprehensive, near real-time synopsis of traffic flow conditions). The main goal of this paper is to discuss the communication protocols employed by various entities in FRIEND. We discuss one of the most fundamental issues in computer networking, which is how two entities can reliably communicate. We start by introducing notation and by establishing terminology that will be used. Then, we discuss how the Road Side Units (RSUs) communicate with different other entities in FRIEND. Also, how data exchange occurs between RSUs and other entities. Then, we explain the communication between Smart Cat's Eyes (SCEs) and other FRIEND entities.

Keywords-Traffic Flow; Incident Detection; Communication protocols; Smart sensors
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I. INTRODUCTION

on most US highways congestion is a common occurrence and, at the moment, advance notification of imminent congestion is unavailable [1]. It has been argued convincingly that given sufficient advance notification, drivers could make educated decisions about taking alternate routes; in turn, this would improve traffic safety by reducing the severity of congestion reducing, at the same time, fuel consumption and carbon emissions [2], [3], [4]. In fact, reducing the number of traffic-related accidents, carbon emissions, fuel usage and travel delays on our roadways and city streets has been recognized as one of the National Grand Challenges. Figure 1 shows the sources of congestion from a national summary.

Traditionally, traffic monitoring was the purview of various federal and state transportation authorities. In support of providing traffic monitoring and data collection functions a series of methods and procedures, known collectively as Intelligent Transportation Systems (ITS) were set up over
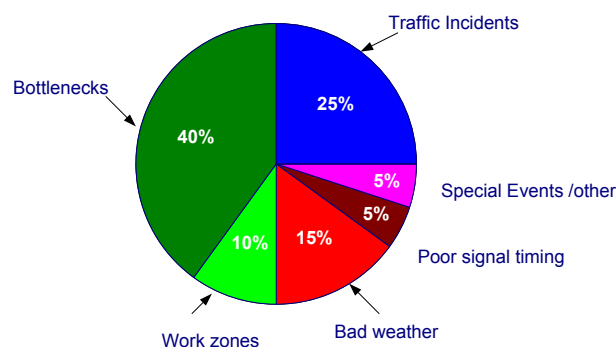

Figure 1. Sources of Congestion

the decades. ITS uses mostly legacy technologies such as inductive loop detectors, magnetometers, video detection systems (e.g. cameras), acoustic tracking systems and microwave radar sensors in conjunction with probe vehicles and other means to estimate traffic parameters [5], [6]. The estimated parameters are then aggregated at a central location (usually a Traffic Management Center) and used for various (mostly statistical) purposes. Up to very recently, the collected data and inferred traffic conditions were not shared with the traveling public. It is well documented that the hardware installed in support of collecting traffic-related data is expensive to install and costly to maintain and repair, making hardware-based traffic data collection and incident detection rather ineffective and inefficient [2]. Not surprisingly, the US-DOT has started to investigate a number of possible alternatives [7], [8], [9].

There is a need for a secure and privacy-aware system that automatically detects existing traffic conditions and anticipates discernible trends in the traffic flow, based on which it can intelligently predict imminent traffic events and alert the driving public to their likely occurrence. Such a system, commonly referred to as a *cyber-physical system* (CPS), must integrate in a coherent way and at various scales the resources and capabilities of its hardware and the software components. We developed a cyber-physical

system that collects data from vehicles, detect incident and propagate information [10].

The rest of the paper is organized as follows. A brief review of FRIEND is given in Section II. Then, the communication protocols are discussed in Section III. Simulation and Evaluation are discussed in Section IV. Finally, Section V is our conclusion and future work.

II. FRIEND

FRIEND can be used to provide accurate information about Traffic flow and can be used to propagate this information. The workhorses of FRIEND are the ubiquitous lane delimiters (a.k.a. cat-eyes) on our roadways that, at the moment, are used simply as dumb reflectors. Our main vision is that by endowing cateyes with a modest power source, detection and communication capabilities they will play an important role in collecting, aggregating and disseminating traffic flow conditions to the driving public. We envision the cat-eye system to be supplemented by road-side units (RSU) deployed at regular intervals (e.g. every kilometer or so). The RSUs placed on opposite sides of the roadway constitute a logical unit and are connected. Unlike inductive loop detectors, adjacent RSUs along the roadway are not connected with each other, thus avoiding the huge cost of optical fiber. Each RSU contains a GPS device (for time synchronization), an active Radio device for communication with passing cars, a radio transceiver for RSU to RSU communication and a laptop-class computing device.

The physical components of FRIEND collect traffic flow-related data from passing vehicles. The collected data is used by an inference engine in the RSUs cyber component to build beliefs about the state of the traffic, to detect traffic trends, and to disseminate relevant traffic flow-related information along the roadway. The contribution of this paper is the development of incident classification and detection algorithm that can be used to classify different types of traffic incident. Then, it can notify the necessary target of the incident.

A. FRIEND: Proposed System

FRIEND is the infrastructure used to implement of incident detection technique, information propagation and build various types of applications. The strongest point of FRIEND is the idea of re-using an already installed infrastructures and just replace the existing nodes with smart nodes. The cat's eyes which are already placed along the road on both sides of a highway. The sensors will be places inside a group of these cat's eyes. These sensors will form a network to disseminate the information about each vehicle to the other nodes of the network. The information about a vehicle (occurrence and location at a particular time) will be forwarded to the other nodes on the road.

Road Side Units (RSUs) already exit on some highways in USA every regular intervals.

III. COMMUNICATION IN FRIEND

A. RSU communication

The RSUs are the entities responsible for communicating with both the vehicles and with other SCEs and neighboring RSUs. As it turns out, in FRIEND, the RSUs play a key role in data collection, in processing the map algorithm, and in the dissemination and propagation of traffic information.

1) Communication between adjacent RSUs: Under normal traffic conditions, adjacent RSUs along the roadway do not communicate with each other directly, relying instead on passing cars to act as *couriers* carrying non time-critical information between them. However, whenever time-critical messages need to be exchanged, adjacent RSUs can, and do, communicate directly for transient periods of time using some form of radio communications, e.g. a DSRC radio interface that covers distances up to 1 km.

In order to make the communication between adjacent RSUs secure, each adjacent pair, say A and B, of RSUs along the roadway (see Figure 2) shares a *time-varying* symmetric key $\mu(A, B, t)$ used to encrypt, at time t, the data exchanged between them. Since the RSUs are synchronous (by virtue of the GPS), they switch from one key to the next in a pre-established order based on their local time.
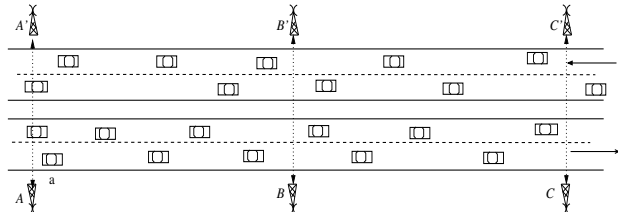
Figure 2. *Illustrating non-time critical communication between adjacent RSUs.*

A communication between adjacent RSUs is in support the propagation of the color-coded traffic status reports to vehicles along the roadway. We anticipate that this kind of communication is low data rate and will involve sending, once a minute or so, an aggregated packet containing the local traffic view of a group of about ten consecutive RSUs.

2) RSU communication with vehicles: The RSUs exchange data with passing vehicles. A car approaching a RSU is either entitled to drop off EDR data with the RSU or else it is considered "new" and is not allowed to do so. Indeed, cars that have completed a handshake with the previous RSU have received a one-time session key α that entitles them to drop off their EDR data upon correctly handshaking with the next RSU. Vehicles that either have just entered the roadway or have failed to handshake with the previous RSU are considered "new" and are not entitled to drop off EDR information with the RSU. Since the RSUs are synchronized, a RSU can easily validate an alleged session-key α. In effect,

using one-time session keys issued by the previous RSU precludes cars (including those stationed by the roadside) from mounting a Sybil attack on the RSU. Also, the session key is independent of the identity of the vehicle allowing for *privacy-preserving* communications between vehicles and RSUs.

3) Data collected and exchanged between RSU and vehicles: Each RSU maintains a headway buffer to save the headway distance over time only if the values are changing, which indicates a change in the density of the traffic.
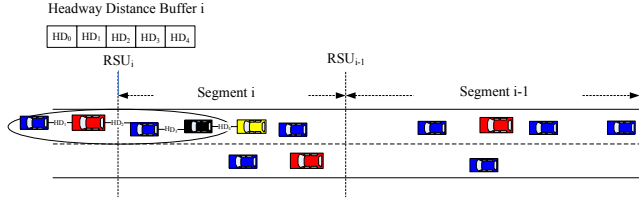

Figure 3.   *Illustrating the headway distance buffer at RSU_i*

4) Evaluating the instantaneous average headway distance: Each RSU maintains a sample average of the most recent headway distance information. This corresponds to the data currently in the headway distance buffer. We define the *Average Headway Distance* (AHD) to be the sample mean of the average headway inferred from the data available in the headway distance buffer.

Let us assume that the headway distance buffer contains the following values:

$$\because HD_1, HD_2, HD_3, HD_4, HD_5$$
$$\therefore AHD = \frac{HD_1 + HD_2 + HD_3 + HD_4 + HD_5}{5}$$

and 1 Unit is

$$1U = AHD + L$$

where L is the estimated length of a vehicle on the highway

$$L \epsilon \{Truck, Vehicle\}$$
$$L = \frac{T\% * L_t + V\% * L_v}{T\% + V\%}$$
where T are Trucks and V are Vehicles
Assume, we have 30% Trucks and 70% Vehicles on the highway
Then $L = \frac{30\% * L_t + 70\% * L_v}{0.3 + 0.7}$
Then $L = 0.30 * L_t + 0.70 * L_v$

Assume that the length of the vehicle is 5 meters, which is the length of a full size car, and the length of the truck on average 15 meters. Then $L = 8$ meters.

5) RSU communication with the SCEs: Assume that the RSUs become aware of an incident. The first task that is performed is to locate the exact segment where the incident

has occurred. Equivalently, this amounts to identifying an adjacent pair of RSUs that flank the incident on both sides.

However, in order to pinpoint the exact location of the incident and that of the corresponding Head and Tail, it becomes necessary for the RSUs to collect speed data from SCEs. A RSU can request information from SCEs in the surrounding area. SCEs can propagate the request to adjacent SCEs until a response is returned back. This type of communication is done on demand only to save power. Communication from RSU to SCEs is done using broadcast. A RSU can send a broadcast message to SCEs requesting information with the direction required.

B. SCE communication

Along with the RSUs, the SCEs are the workhorses of FRIEND. The SCEs play the role of having an exact view of the highway all over the segments. Although SCEs work only on demand in case of sudden change of traffic pattern, their main jobs are:

1) to communicate with vehicles on the highway to collect information about the traffic flow;
2) to identify (on demand) the exact location of an incident or event;
3) to keep track of Head (the beginning of a backup) and Tail (end of a backup) of an incident.

Although there are three different types of communication involving SCEs. These types of communication can be working simultaneously and even can give a feedback from one to other. Using different types of technology helps in avoiding collisions. However, power consumption is important in SCEs, so most of the communication is done only when requested, as shown in Figure 4, the following three types of communication involving the SCEs are:

1) communication from SCEs to RSUs,
2) communication between adjacent SCEs,
3) communication from vehicles to SCEs.

1) Communication between SCEs and RSUs: The SCEs respond to a request sent from the closest RSU. We use simple narrow-band FSK radio data transmitters that turn on within milliseconds and draw only 10-20mA. Adjacent-channel interference and jamming are very real problems, but can be mitigated by using a frequency-agile narrow-band system. Since this communication does not require a high data rate, we choose to use narrow-band FSK data transceivers in SCEs, as in [11].

Each SCE randomly selects a time slot within a 60-second interval and transmits there. If it detects that another SCE is present when its randomly selected transmission time arrives, it waits for it to pass before transmitting. Redundancy and sparse use of the channel reduce the probability of collisions to an acceptable level.

For a sparse time-multiplexed network with n nodes and s time slots, the probability of no collisions during a cycle is
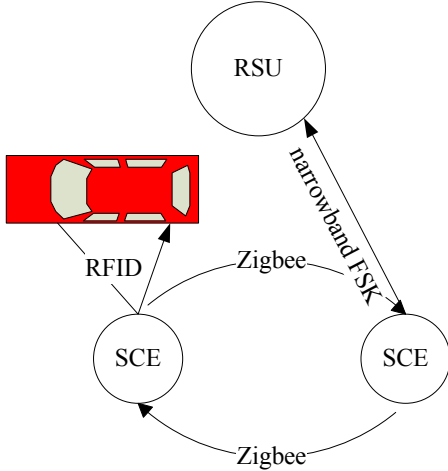
Figure 4. *Three different types of communications for SCEs.*

$$P(nocollisions) = \frac{C(s,n)}{C(n+s-1,n)}$$

Where $C(s,n)$ is the number of combinations that do not involve a collision and $C(n+s-1,n)$ total number of combinations.

With n=10 per RSU (which means in this case that RSU can communicate with 10 different SCEs), there is a 1.2% chance of a collision per minute. The chance of a collision occurring during two consecutive 60-second intervals, assuming good random number generators in the nodes is (1.2% * 1.2%)= 0.014%, so the expected time between any two consecutive collisions is about two hours. However, the expected time between collisions that cause data loss is greater, because the collisions would have to involve the same node [11].

The packet format is shown in Figure 5 [11]. The first field is the packet info, which can be the system type, software version and any other information. Then, comes the node ID, and we assume that the SCE ID will take around 2 bytes which gives $16bits$. Next is information about vehicles, including the average speed and the count of vehicles involved, we assume 18 bytes (as in [11]). Then, in case of information sent to another SCE to check the speed and density measured in the middle of the segment, another node ID 2 is included with data from SCE 2. Finally, an unused space is reserved for future enhancements (e.g. security).

2) Communication between adjacent SCEs: The SCEs are networked together in order to request information about

Packet Info	SCE ID	Information about Vehicles in segment [i, i-1] (Average Speed, Count)	SCE ID 2	Recorded data at SCE ID 2	Unused space

Figure 5. *Packet format for data sent from SCE to RSU.*

the highway flow traffic condition in middle of a segment or to identify the location of an incident. This type of communication happens only on demand and it is in the case of an incident in the middle segment that cannot have a direct communication with a RSU.

As mentioned before, in case of an incident that occurs on the highway, the first concern is to identify the pair $RSU-RSU[i,i+1]$ of RSUs that flank the segment where the incident occurred. It can be done by asking each RSU what flow it has seen and by propagating the question until identifying the $RSU-RSU[i,i+1]$ where the incident takes place as shown in Section III-A.

Second, RSU_i and RSU_{i+1} send a broadcast request to the SCEs in the nearby area to request the exact segment of incident. When RSU_i broadcasts its request, only the SCEs in the direction of traffic will start the process. And when RSU_{i+1} broadcasts its request, only the SCEs in the opposite direction of traffic will start the process as shown in Figure 6.
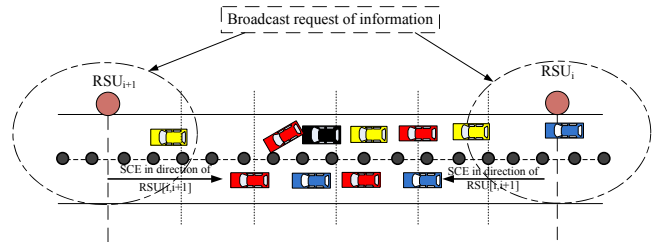

Figure 6. *RSU requesting information from SCEs in the direction of RSU-RSU[i,j].*

Third, after sending the request to SCEs, the request is propagated to identify the segment of an incident. Both sides of SCEs propagate the request to the next segment of SCEs as shown in Figure 7. The moment a reply is received, information is sent back to the RSU to inform adjacent RSUs.
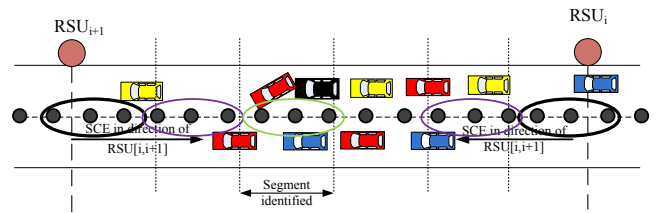

Figure 7. *SCEs identifying the segment of an incident.*

We note that the chance that the SCEs need to communication with other SCEs is equal to the chance that the incident or event occurs in the middle of one of the segments. Assuming we have six segments, then the chance is $\frac{1}{3}$.

3) Communication from vehicles to SCEs: FRIEND assumes the use of RFID technology as the communication medium between the smart wheels and SCEs. The details of

the RFID-based communication that takes place between the smart wheels of vehicles and SCEs follows. The RFID reader in the smart wheels allows the vehicle to inform the SCEs about speed, stability loss due to road conditions (if any), and ambient temperature. The SCEs collect data sent from vehicles every $\triangle t$, where t depends on highway conditions. The RFID reader in the smart wheels transmits an object identity using electromagnetic waves. In the SCE, an RFID tag stores its ID in memory. The RFID reader which is installed in the vehicle wheels emits RF radio waves eliciting a signal back from the tag. We use RFID with a radio range up to approximately 3m. The most important benefit of an RFID tag is the battery-free operation. A tag works without a power source since it gathers energy from a reader's waves [12].

IV. SIMULATION AND EVALUATION

In the simulation, we compare two scenarios to evaluate the optimal value for the number of Cat's eyes needed. First scenario, in a high density highway; sensors are always in the awake mode, we assume that if two vehicles exist at the same area of the same node that will conclude a collision in sensing; and both messages are dropped. The second scenario, we try our model in the sleeping mode(where nodes go to sleep every couple of mins). In both scenarios, we don't allow vehicle-to-vehicle communication and we try to calculate the optimal value for the cluster size. Then, we have two cases,*case I*:No sleeping mode is implemented (sensors are always awake) and *case II*:Sleeping mode is implemented.

A. Simulation Settings

We evaluate our frame work using ONE simulator [13], which is the Opportunistic Network Environment simulator that used to generate node movement using different movement models, route messages between nodes with various routing algorithms and sender and receiver types. It allows to visualize both mobility and message passing in real time in its graphical user interface. In the simulation, our model uses a two lane highway of size 11 miles which describes a part of the Highway US-13 that goes beside the East coast from Virginia to New York. We generate vehicles randomly from the start points. The model assume a fixed stations between the two lanes which represents our nodes (Cat eye's) along the highway, we call it (Group I fixed nodes). These stations are 24.384 meters (80 feet) apart from each other. Each vehicle - we call it (Group II moving nodes) broadcast a packet every 2 seconds in the range of a circle with radius 12.192 meters (40 feet). Our model compares the ratio of messages dropped over all messages. The simulation parameters and values are listed in Table I. Figure 6 shows our simulation; the left side shows our cat eyes nodes with the sensing area in the range of 167 feet (500 meters) and the right side shows our map $US13$.

Table I
SIMULATION SETTINGS

| Parameters	Values
Number of Lanes	Two
Highway Length	≈11 miles
No. of groups on the highway	Two
Buffer size for two groups	10
Group I Max Speed	zero mile/hr
Model Movement Group I	Stationary Movement
Group II Max Speed	100km/hr=55 mile/hr
Model Movement Group II	Map based Movement
Simulation Time	30 min= 1800 sec
GUI Map	Head northeast on US-13 11.2 mi
Model Movement	StationaryMovement
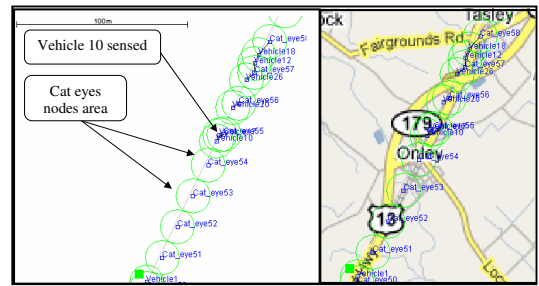
Figure 8.   Simulation- Left A - Right B

B. Evaluation

In evaluation, simulation data is analyzed to get the optimal value of cluster size. our first scenario, we calculate the cluster size (number of nodes required) in order to detect all vehicles moving with maximum speed of 55mile/hr, simulation results are taken and analyzed assume the three different cases (size of 2,3 and 4). We expect that the larger the size of the cluster, the more able to detect the vehicles on the Highway. At the same time , we cannot increase the cluster size more than 4 nodes as it will disconnect clusters and prevent cluster communication.

1) Scenario A: No Sleeping Mode: As shown in figure 9, in each four nodes of Cat's eyes, at least two should be smart nodes.

2) Scenario B: With Sleeping Mode: In the second scenario, we assume that the traffic is low density traffic which presents the night mode highway traffic or constructions on the highway. Our nodes will sleep for 10 mins and wake up for 10 mins. As shown in figure 10 , no vehicles are detected the first 10 mins, then the percentage starts to raise up , it reaches about 50 % at the end of the 20 mins then starts to decay at the end. It is also clear that the difference between cluster sizes are small, this is because that fact that low density road will not allow any collision when sensing the vehicles but high speed vehicles still may not be sensed.

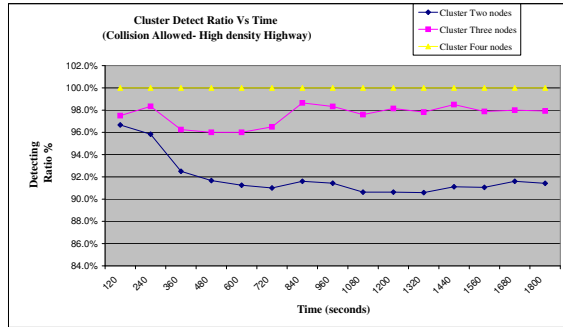In summary, our results show that four nodes cluster is
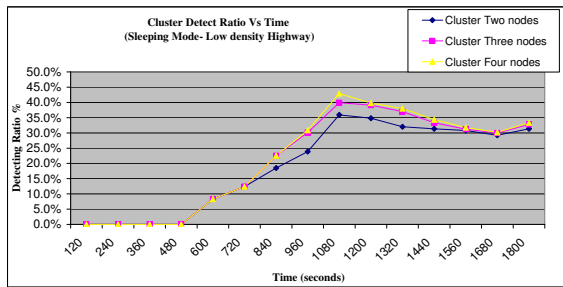
Figure 9. Simulation- results - Awake Mode

Figure 10. Simulation- results - Sleeping Mode

sufficient to detect vehicles over the highway and calculate there average speed. Also, our system will be working in case of dead nodes, in case of one or two nodes is dead, cluster can still calculate speed and forward information to other clusters. In case of three nodes died, cluster will not be able to calculate speed or information but still can forward information. In case of all four nodes are dead, cluster to cluster communication is still valid as the last node in the pervious cluster can communicate with the first node in the next cluster (in communication range). Finally, the case where two consecutive clusters are dead , this will result in a gap in our system which is expected not to happen unless on purpose maintenance.

V. CONCLUSION

we have addressed the communication protocols employed by each of the entities in FRIEND. We explained how RSUs communicate with adjacent RSUs, vehicles, and SCEs. We also evaluated the average headway distance. The communication protocols for the SCEs with RSUs, adjacent SCEs, and vehicles are described in detail. Our future work is to discuss the desicion making in FRIEND and to update our simulator presented in [10].

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