

Safe-aaS: Decision Virtualization for Effecting Safety-as-a-Service

Chandana Roy, *Student Member, IEEE,* Arijit Roy, *Student Member, IEEE,*
Sudip Misra, *Senior Member, IEEE,* and Jhareswar Maiti

***Abstract*—In this paper, we present solution for the development of a novel infrastructure, *Safety-as-a-Service* (*Safe-aaS*) for the road transportation industry. Safe-aaS provides safety related decisions to the registered end-users. The safety decisions are customized as per the end-user types and their requirements. Existing related research work on road safety focus on the development of the safety systems, which are able to assist the driver of the vehicle. However, none of the works serves as a common platform for providing customized decisions dynamically as per user requirements. As per our knowledge, Safe-aaS is one of the first attempts in its domain, where multiple end-users receive safety related decision dynamically. An end-user enjoys the pay-per-use service of Safe-aaS, without concerning about the back-end process. Safe-aaS is based on *Service Oriented Architecture* (SOA), where different business entities such as vehicle owners, sensor owners, Safety Service Provider (SSP), and end-users are involved. We introduce the term, *decision virtualization*, which enables multiple end-users to access the customized decisions remotely. We present possible cost analysis for the entities involved in the system. Analytical results show the cost and profit analysis of the different entities. We observe the profit gain by mobile sensor owner is 19.69% more as compared to static sensor owner. In the presence of 5, 10, and 15 end-users, payable rent varies between $15\% - 20\%$. Additionally, we present two case studies to depict a clear view of usage of Safe-aaS.**

***Keywords*—Road Transportation, Service Oriented Architecture (SOA), Decision Virtualization, Safety Service.**

I. Introduction

In the last few years, Industrial Internet of Things (IIoT) [1], [2] technologies have emerged to be popular in the industries. Internet of Vehicles (IoV) is an imperative domain of IIoT, which is designed for handling traffic smoothly in the transportation industry [3]. In order to improve traffic system, IoV implements Intelligent Transportation System (ITS) [4]. On the other hand, mobile crowd sensing (MCS) [5] has led to increase in the application of mobile devices for sensing, computation and storage of data. However, due to lack of prompt and correct information, casualty increases in road traffic transportation industry.

In this work, we propose a Service Oriented Architecture (SOA)-based safety infrastructure, Safe-aaS for use in the road transportation industry. In this infrastructure, end-users, such as drivers and vehicle owners, receive proper decision with the help of the *pay-per-use* model. Typically, an end-user registers himself/herself with this infrastructure through a Web portal. Thereafter, the end-user is able to choose decision parameters among the available ones. On the contrary, heterogeneous sensor nodes are attached to vehicles and deployed over different geographical locations, which sense and transmit safety related data either to the edge devices or the cloud, based on the requirements. We use edge devices to reduce the latency and bandwidth consumption in data processing. Further, different safety related information are produced from sensor data. Based on these information, *decision virtualization* is effected. Moreover, the decision is customized and shared among multiple end-users as per request.

C. Roy and J. Maiti are with the Department of Industrial & Systems Engineering, A. Roy is with the Advanced Technology Development Centre, and S. Misra is with the Department of Computer Science and Engineering, Indian Institute of Technology Kharagpur, India, Email: {chandanaroy, arijitroy, sudipm}@iitkgp.ac.in, jmaiti@iem.iitkgp.ernet.in

A. Motivation

With the significant increase in the number of vehicles on the road, safety becomes an essential aspect of concern for both drivers and user organizations in the transportation industry. The prior information to vehicle owners, drivers, and user organizations about the road conditions, weather, maneuver detection, probability of road accidents, and fatality reduce the risk of accidents. This serves as the motivation for proposing a novel architecture, *Safety-as-a-Service* (*Safe-aaS*), where an end-user receives decisions related to road safety on a rental basis. The inconveniences faced by the end-user for deployment, maintenance, and reallocation of sensor nodes are ameliorated with the help of this architecture. In the proposed architecture, we introduce the concept of *decision virtualization*, which helps in receiving different customized decisions related to safety to multiple end-users from different geographical locations. However, an end-user pays the rent for the service as per the chosen decision parameters. Safe-aaS provides real-time decisions related to road to certain locations, before actually reaching the destination.

B. Contribution

The primary contribution of this work is to propose an SOA-based architecture to impart safety decisions to multiple users simultaneously. The specific *contributions* of this work are:

- We propose a new and unique architecture for use in the road transportation industry, which provides safety related decisions to the end-users. This architecture is one of the first attempts in the domain for evolving intelligent transportation systems.
- We introduce the novel concept of decision virtualization to meet the requirements for serving the safety related customized decisions to the multiple end-users.
- In Safe-aaS, multiple actors are involve along with the end-user payments. Thus, we discuss thoroughly the possible business model for Safe-aaS, which helps in the distribution of payment among the actors.
- We characterize the proposed architecture mathematically, along with rigorous simulation results.

The rest of the paper is organized as follows. Section II describes the related research works done in the area of road

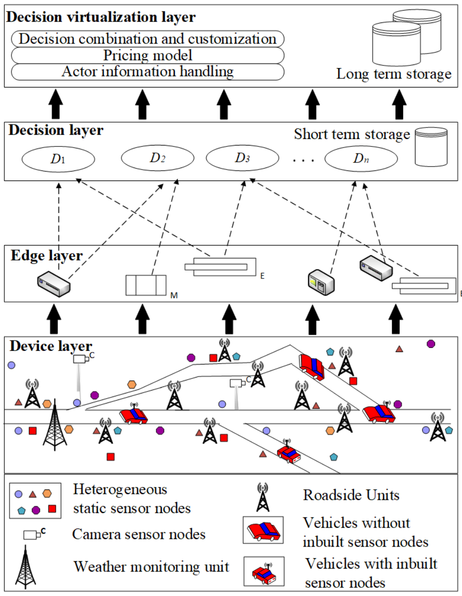


Fig. 1: Safe-aaS: The System Architecture

transportation. The system architecture and cost analysis of Safe-aaS is described in Section III. The proposed architecture, Safe-aaS, is evaluated in Section IV. Finally, the work conclude in Section V, while citing directions for future work.

II. Related Work

In this section, we discuss the prior works in the domain of road transportation. Glaser *et al.* [6] proposed a two-step algorithm, which is executed for trajectory planning of autonomous vehicles. The proposed scheme suggests the trajectory of the vehicle for the next time instant. Due to high traffic volume and limited resources, the vehicles are unable to interact with neighboring vehicles, as a consequence of which, the vehicles are unable to chose their trajectory independently. Considering these on-road constraints, Song *et al.* [7] designed a car-following model, which is based on a motion model in a single lane road. Their solution provides road-map and motion dependence information to the moving on-road vehicles. Sirmatel *et al.* [8] designed a macroscopic fundamental diagram-based economic predictive model to improve the mobility in heterogeneously congested large-scale urban networks. In another work related to the mobility in urban environment, authors [9] proposed the mobility model for vehicles, pedestrians and communication among them using multi-objective optimisation and multi-criteria decision making. To distribute the road hazard warning (RHW) message distribution to distant vehicles, Daniel *et al.* [10] proposed a mechanism for cluster-head selection. Their solution ensures reduced latency for transmitting RHW messages while selecting a stable cluster-head. Further, Nikookaran *et al.* [11] proposed an Integer Linear programming (ILP) problem to minimize the sum of capital expenditure and operating expenditure in vehicular roadside unit (RSU) replacement. They formulated the problem in two parts – offline design and online performance. Offline design provides knowledge of set of RSUs placed, while online design evaluates the quality of the offline design.

Certain systems are also developed for the real-time assistance and safety of drivers on road. Fazeen *et al.* [12] designed a mobile smartphone-based system to record and analyze the driver's intentions, a vehicle's condition, and overall road conditions using three-axis accelerometer. The auditory alerts generated from the real-time data analysis by the authors helps in increasing driver's awareness in order to improve road safety. Bertolazzi *et al.* [13] designed a driver-support system to maintain safe speed and distance with vehicles. Authors focus on the integration of various safety aspects on road such as implemented driver support system to assist safe distance between vehicles on the road, lane changes, maintenance of safe speed, and collision avoidance. Another work which proved to be advantageous towards road transportation, was done by Angelos *et al.* [14]. They proposed the cognitive architecture, called INSAFES, where safety in road transportation was considered. They defined three different levels in the framework, viz. perception, decision, and action. Additionally, the authors developed a warning manager, which independently combines the requests, prioritizes them, and interacts with the user.

Synthesis: Although researchers addressed many problems related to road safety, no literature renders a common platform for providing safety related decision to end-users. In the existing literature [13], [14], the authors focus on the integration of various safety aspects of the road. The decision and action levels developed by authors assist the driver during lane-changes, maintaining safe distance, safe speed and avoiding collision with neighboring vehicles. However, the decisions produced are not communicated to multiple users simultaneously. Our work describes an architecture to provide safety related decisions to multiple users on request. Moreover, the end-users are able to access decisions based upon various parameters from remote geographical locations concurrently through the newly introduced concept of decision virtualization.

III. Safe-aaS Infrastructure

A. System Architecture

Safe-aaS is based on SOA, in which an end-user requests safety related services through a Web portal. Based on an end-user's request, response is provided in the form of a decision by the Safe-aaS service provider (SSP). The architecture takes a dual-perspective as follows:

End user's perspective: An end-user registers him/herself with the Safe-aaS by providing all necessary information. After the completion of the registration process, the end-user enters the source and destination addresses using two fields – *StartFrom* and *EndTo*. Further, the registered end-user selects decision parameters to receive the decision service. For simplicity, we consider lane-change, curve warning, safe inter-vehicular distance, road condition, and past history of accidents as decision parameters. Based on the selection of decision parameters, Safe-aaS provides the decision to the end-user about what s/he should do next, while he is traveling on the same stretch of road. The end-user only pays the amount for the decision service based on the number and types of decision parameters. Depending upon the number of sensor nodes involved in generating the decision requested by the end-user, the rental fee paid by him/er is decided. However, the end-user is unaware of the back-end process.

Analytical perspective: The Safe-aaS infrastructure is based upon five layers, which are as follows:

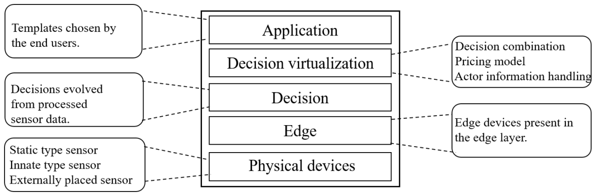


Fig. 2: Block diagram

Device Layer: This layer consists of heterogeneous physical sensor nodes. These nodes are static and of innate type. Fig 1 shows the various sensor nodes present in the device layer in Safe-aaS infrastructure. Further, static sensor nodes are of two types – scalar and camera, which are deployed over different geographical locations. Scalar sensors provide non-visual data such as road and weather conditions. The camera sensor node imparts information regarding traffic, detection and monitoring of on-road vehicles, and accident data. The innate type sensor nodes are those that are built into vehicles, which render instruction regarding the rim, tire, load, and speed of the vehicles. Sometimes innate sensor nodes may be deployed on the vehicle by the sensor owners.

Edge Layer: This layer is responsible for processing time sensitive raw sensor data. In road safety, time is a crucial factor for data processing and making a decision. Thus, all time-critical data are processed in different edge devices. As the vehicles are mobile, the edge nodes are chosen dynamically for processing the data in order to make decision. If the data received from the device layer are not time sensitive, the data are further transmitted to the cloud-server.

Decision Layer: The processed sensor data from the edge devices are delivered to the decision layer. Further, the combined processed sensor data received from multiple edge devices generate decision [13]–[15]. As shown in Figs. 1 and 2, decisions are generated from the inputs provided from the edge layer devices or cloud-server.

Decision Virtualization Layer: In Safe-aaS, end-users request decision services from different geographical locations. This layer is responsible for the logical mapping among decisions and end-users. The concept of *decision virtualization* is introduced in this layer. Using this concept, a single decision is shared among multiple end-users. However, the end-user gets an illusion that the decision is created only for his/her service. The decision virtualization layer executes the decision parameters inserted by the end-user, while executing service requests, in order to create a decision, as illustrated by the block diagram in Fig. 2. Based on the decision parameters, different end-users receive decisions related to safety, as per his/her requirements.

Application Layer: The application layer acts as the interface between the end-users and Safe-aaS. An end-user registers him/her with the system through this layer in order to receive the requested service(s). The payment option along with the selection of decision parameters is needed to be chosen from this layer by an end-user.

B. Safe-aaS: Mathematical Model

In the Safe-aaS architecture, based on time-sensitiveness, the primarily processed sensor data from the edge layer are delivered either to the decision layer or further transmitted to the cloud-server. In the decision layer, various processed sensor data are combined to generate a decision. The decision layer stores the decisions for a short duration. Further, the generated decisions are transmitted to the decision virtualization layer. Based on the number of users requests and their selected decision parameters the decision are virtualized. Further, the virtualized decisions are accessed by multiple end-users belong to various geographical regions at the same time instant. The Safe-aaS infrastructure consists of four key active components – vehicle owners, sensor owners, safety service provider (SSP), and end-users. Typically, drivers of vehicles (including heavy and personal), government agencies, and owners of the vehicles are the end-users of Safe-aaS. A set of end-users is represented as $\mathbb{E} = \{E_1, E_2, \cdots, E_n\}$.

***Definition* 1.** *Safety Service Provider (SSP) is a centralized entity in the system, which is responsible to manage the whole Safe-aaS infrastructure.*

Sensor owners deploy heterogeneous sensor nodes over different geographical locations and acquire monetary benefit based on the utilization of the sensor nodes by Safe-aaS. Let us consider the set $\mathbb{S}$ of sensor owners, where $\mathbb{S} = \{\mathcal{S}_1, \mathcal{S}_2, \cdots, \mathcal{S}_k\}$, and $\mathcal{S}_i \in \mathcal{S}$, $1 \leq i \leq k$. Thus, total k sensor owners are associated with Safe-aaS. We classified the vehicle owners into two types – active and passive.

***Definition* 2.** *Active vehicle owner refers to the owner of those vehicles in which physical sensor nodes are built into the vehicles.*

***Definition* 3.** *Passive vehicle owner refers to the owner of the vehicles in which sensor nodes are not built into them, but the sensor nodes are deployed by other sensor owners.*

We consider $\mathbb{V} = \{\mathcal{V}^a, \mathcal{V}^p\}$ as the set of vehicle owners, where $\mathcal{V}^a$ and $\mathcal{V}^p$ denote the set of active and passive vehicle owners present in the system. Any i^{th} active vehicle owner is V_i^a, such that $V_i^a \in \mathcal{V}^a$ and $1 \leq i \leq l$. Similarly, V_j^p denotes the j^{th} passive vehicle owner, such that $V_j^p \in \mathcal{V}^p$ and $1 \leq j \leq m$. Any active vehicle owner, V_i^a, has S_f^{in} set of inbuilt sensor nodes. Similarly, in the vehicle of the passive vehicle owner, V_i^p, sensor owner, $\mathcal{S}_i \in \mathbb{S}$ deployed a set of physical sensor node is represented by S_d^{ex}. Additionally, the set of static sensor nodes present in the Safe-aaS is denoted by S^{st}. Each sensor owner $\mathcal{S}_i$ deploys S_b^{st} $(1 \leq b \leq x_1)$ type of heterogeneous sensor nodes at various geographical locations. The number of active static sensor nodes at any time instant, τ, of any sensor owner, $\mathcal{S}_i$ is y, where $\mathcal{S}_i \in \mathbb{S}$ $(1 \leq y \leq x_1)$. Therefore, the set of heterogeneous sensor nodes, S, present in the system is represented as $S = \{S^{st}, S^{ex}, S^{in}\}$. The total number of sensor nodes N_{S_t} at any time instant (t) is mathematically expressed as:

$$N_{S_t} = (x_1 + x_2 + x_3) \tag{1}$$

where x_1, x_2, and x_3 represent the total number of static, inbuilt, and external sensors present in the system at t^{th} time instant.

***Proposition* 1.** *The mapping F from the set of static sensor nodes S^{st} to set of sensor nodes S is a set-valued map.*

Proof: We consider F to be a function, which maps the set of static sensor nodes, S^{st}, to the set of sensor nodes, S. Therefore, S is the co-domain and S^{st} is the domain of F. For each static sensor, $S_i^{st} \in S^{st}$ $(1 \leq i \leq x_1)$, where S^{st} a non-empty set, $F(S_i^{st})$ is a subset of S. Mathematically,

$$F : S^{st} \rightrightarrows S, \text{if} \quad S_i^{st} \in S^{st} \text{and} \quad F(S_i^{st}) \subseteq S \tag{2}$$

Therefore, F is a set-valued map or multivalued function from S^{st} to S. ■

Similarly, the function F' is a set-valued map from S^{ex} to S and the function F'' is also a set-valued map from S^{in} to S.

Each physical sensor node present in the device layer is represented as a 6-tuple.

$$S = \langle type, sense, id, loc, \mathbb{O}, \mathbb{R} \rangle \tag{3}$$

The *type* of a physical sensor node represents whether the sensor node is static/innate type. In a sensor node, different types of sensor are possible to be integrated. Thus, *sense* represents the type of sensor integrated with the node. Each physical sensor node has an unique identification number, which is represented as *id*. The geographical location of any physical sensor node is denoted as $loc = \langle lat, lng \rangle$, where lat and lng represent the latitude and longitude of the sensor node, respectively. Further, the sensor node either belongs to a sensor owner, $\mathbb{S}$, or a vehicle owner, $\mathbb{V}$. Therefore, the set of owner of physical sensor nodes and vehicles is represented as, $\mathbb{O} = \{O_i : O_i \in (\mathbb{S} \cup \mathbb{V})\}, \forall i \in \{1, 2, \cdots, g\}$.

In the existing literature various reputation schemes are discussed [16]–[18]. However, we have computed the parameter *Reputation*, $\mathbb{R}$, to quantize the performance of sensor nodes as represented in Equation (11). In order to quantify the reputation, we compute the effective utility, $\mathbb{U}^{eff}$ of a sensor node. The effective utility, $\mathbb{U}^{eff}$, is defined as the degree of usefulness of the sensor node in terms of the residual energy (ξ_t^{resi}) at any time instant, t, energy utilized for sensing (ξ_t^{sens}), transmission (ξ_t^{trans}) by a sensor node, distance between the sensor node and edge node or cloud ($D_t^{S_i,e}$), and communication range (r_c). The ξ_t^{trans} of any sensor node varies at every time instant with the increase/decrease in $D_t^{S_i,e}$. Moreover, $D_t^{S_i,e}$ is always less than or equal to the communication range of sensor node. With the fluctuation in ξ_t^{trans} of the sensor node, the ξ_t^{resi} of the corresponding sensor node also changes. Therefore, ξ_t^{resi} varies with $D_t^{S_i,e}$. $\mathbb{U}_t^{eff}$ of any sensor node is calculated as:

$$\mathbb{U}_t^{eff} = \frac{\xi_t^{sens}}{\xi_t^{trans}} \left(\frac{\xi_t^{resi} \times r_c}{\xi^{init} \times D_t^{S_i,e}} \right) \tag{4}$$

where $D_t^{S_i,e}$ denotes the Euclidean distance between the sensor, S_i, and edge node/ cloud, e, at the t^{th} time instant and ξ^{init} represents the initial energy of the sensor.

The state St of any physical sensor node is represented as:

$$St = \begin{cases} 1, & \text{sensor is active} \\ 0, & \text{otherwise} \end{cases} \tag{5}$$

Therefore, from Equation (5), the state of any static sensor node S_x^{st} ($S_x^{st} \in S^{st}$) over a time interval $T = \{t_1, t_2, \cdots, t_n\}$ is expressed in Equation (6).

$$S_x^{st} = [1 \quad 1 \quad 1 \quad 0 \quad 0 \quad \cdots\cdots \quad 1] \tag{6}$$

Theorem 1. *In any application area, over a time interval, T, the join of zero-one matrix of the relation, R, on the state of a sensor node, provides the transitive closure of the matrix.*

Proof: Let the zero-one matrix, M_R, of the relation, R, on the state of sensors, S, over time period, T, be represented as:

$$M_R = \begin{bmatrix} 1 & 1 & 1 & 0 & 0 & \cdots & 1 \\ 1 & 0 & 0 & 0 & 1 & \cdots & 0 \\ 0 & 1 & 1 & 0 & 1 & \cdots & 1 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \cdots & \vdots \\ 1 & 0 & 0 & 0 & 1 & \cdots & 1 \end{bmatrix} \tag{7}$$

M_R is the zero-one matrix of order $(n \times N_S)$. The transitive closure R^* is expressed as:

$$M_{R^*} = M_R \vee M_R^{[2]} \vee M_R^{[3]} \vee \cdots \vee M_R^{[N_S]} \tag{8}$$

where $M_R^{[2]}$ is the *Boolean product* of $M_R \odot M_R$, i.e. $(M_R \wedge M_R) \vee (M_R \wedge M_R)$ and $M_R^{[N_S]}$ is the Boolean product of N_S factors of M_R. ■

The possible states of a sensor node are either active or inactive. Thus, in order to determine $\mathbb{R}$, we observe the average number of times a physical sensor node was active over a time interval. We use *exponential moving average* for calculating the average number of times the state of the sensor node was active. The average state of the sensor ($St^{avg}(t)$) at any time instant t is defined in Equation (9).

$$St^{avg}(t) = \alpha St(t) + (1 - \alpha) St^{avg}(t - 1) \tag{9}$$

where α is any constant smoothing weight factor, which consider the importance of old observations, where $0 \leq \alpha \leq 1$. The packet delivery ratio, $\mathbb{P}_t$, at any time instant, t, is considered as the factor to measure the number of data packets successfully delivered to the edge node. $\mathbb{P}_t$ is expressed as:

$$\mathbb{P}_t = \frac{n_d^{se} - n_d^{dr}}{n_d^{se}} \tag{10}$$

where n_d^{se} and n_d^{dr} are the number of data packets sent and dropped respectively, at the t^{th} time instant. Finally, $\mathbb{R}$ is considered to determine the performance of any sensor node, $S_i \in S$. The reputation comprises of three parameters average state ($St^{avg}(t)$), packet delivery ratio ($\mathbb{P}$), and effective utility ($\mathbb{U}^{eff}$). $\mathbb{R}$ is mathematically expressed as:

$$\mathbb{R} = St^{avg}(t) \times \mathbb{P}_t \times \mathbb{U}_t^{eff} \tag{11}$$

Let $\mathcal{E}$ denote the set of edge devices present in the edge layer, where $\mathcal{E} = \{e_1, e_2, \cdots, e_\theta\}$. As per the services requested by the end-user, various processed data from the sensors are integrated to yield a decision, $D_i \in \mathbb{D}$, where $\mathbb{D}$ denotes the set of possible decisions. Any decision, D_i, is produced by combining q ($q \in \theta$) number of processed sensor data obtained from the edge layer or cloud-server.

***Proposition* 2.** *The mapping function, $\mathcal{F}$, from set of edge devices at any time instant, t, to the set of decisions produced in the decision layer to serve the end-user's request is surjective (onto).*

Proof: We assume codomain of $\mathcal{F}$ is the set of decisions and the domain is the edge devices at which the raw sensor data is processed. Every element in the codomain has pre-images in the domain. Thus, multiple sensor data are fused to produce a decision [15].

$$\mathcal{F}(D_i) = \{\mathcal{E}_i | \mathcal{E}_i \in \mathbb{E}\} \Longrightarrow \mathbb{E} \neq \phi \tag{12}$$

Therefore, we conclude that to serve any end-user's request, mapping function, $\mathcal{F}$, is surjective. ■

The decision, D_i, to be delivered to the end-user, E_x, is expressed as a 3-tuple, $D_i = \langle D^{type}, D^{intv}, D^{area} \rangle$. The 3-tuple of decision, D^{type}, D^{intv}, and D^{area} represent the various parameters requested for the decision, duration for which the decision is requested, and the area or location over which the parameters are requested. The mapping of any decision, D_{E_x}, to be delivered to the end-user, E_x, to the set of decisions in the decision layer is represented by the function, f, such that $f(D^{type}, D^{intv}, D^{area}) : D_{E_x} \rightarrow \mathbb{D}'$. Further $\mathbb{D}'$ is expressed as $\mathbb{D}' \subset \mathbb{D}$ and $\mathbb{D}' = \{D_i | D_i \in \mathbb{D}\}$. Depending upon the decision requested by the end-user, a set of decisions is selected from the decision layer and is combined using the function f.

C. Cost Analysis

In order to receive decisions, an end-user pays rent for Safe-aaS infrastructure. Thus, there exist cash inflow and outflow of different actors in this architecture. We consider four active components in Safe-aaS – sensor owner, vehicle owner, SSP, and end-user. A sensor owner deploys sensor nodes over different locations or in vehicles. Therefore, for the deployment and maintenance of these sensor nodes, different costs are involved. The cost outflow for any sensor owner is mathematically represented as follows:

$$C_{\mathcal{S}_k} = C_{fixed} N_{\mathcal{S}_k} + C_{variable} N^{active}_{\mathcal{S}_k} \quad (13)$$

where $C_{\mathcal{S}_k}$ is the cost incurred by the k^{th} sensor owner. C_{fixed} and $C_{variable}$ represent the fixed and variable costs respectively. Further, $N_{\mathcal{S}_k}$ and $N^{active}_{\mathcal{S}_k}$ are the number of static sensor nodes deployed by the sensor owner, $\mathcal{S}_k$, and the number of sensor nodes active during the time period, T, respectively. Fixed cost, C_{fixed}, is the sum of the cost of the i^{th} sensor node, C_{S_i}, and the cost of deploying, C_{deploy}, the physical sensor nodes. Mathematically,

$$C_{fixed} = (C_{S_i} + C_{deploy}) \quad (14)$$

The variable cost, $C_{variable}$, is the cost incurred due to regular maintenance, $C_{maintain}$, of the sensor nodes over a month. Similarly, cost outflow, $C_{V^a_j}$, of the j^{th} active vehicle owner, is represented as :

$$C_{V^a_j} = C_{variable} N^{active}_{V^a_j} \quad (15)$$

where $N^{active}_{V^a_j}$ is the number of sensor nodes active during the time period, T. Since the active vehicle owners have inbuilt sensor nodes in their vehicles, the fixed cost due to procurement and deployment of sensor nodes is not considered. The passive vehicle owners may wish to integrate physical sensor nodes in the vehicle for providing the services to Safe-aaS. Thus, the cost outflow for the sensor deployment and maintenance is calculated in the same way as in Equation (13). Moreover, the fixed and variable costs are paid by the sensor owner who deploys sensor nodes in the vehicle. Additionally, the passive vehicle owner earns profit in the form of rent paid by the sensor owner for deploying sensor nodes on the vehicle. Therefore, the profit of any j^{th} passive vehicle owner, V^p_j, increases with the increasing number of sensor nodes deployed on the vehicle. An end-user adopts a pay-per-use model in the Safe-aaS architecture. Consequently, cost outflow of end-users registered to Safe-aaS of the i^{th} SSP, $SP_i \in \mathbb{SP}$ are calculated as:

$$C_{E_k} = C^i_{tmpc} t_{use} - C_{pn} \frac{(t_{rcv} - t_{allw})}{60} - C^i_{tmpc} d \quad (16)$$

where C_{E_k} represents the rent paid by the k^{th} end-user. C^i_{tmpc} is the per unit cost based upon the number of decision parameters chosen by the i^{th} end-user and t_{use} is the time duration (in minutes) for which the end-user requests the service. The per unit penalty cost, C_{pn}, is deducted from the rent of the end-user, if the requested services are delivered with significant delay above an allowable time period limit, t_{allw}. Therefore, $(t_{rcv} - t_{allw})$ is the time duration during which the penalty cost is levied upon, if the safety decision is delayed. The time instant when the end-user receives the decision, is denoted by t_{rcv}. We consider another discount factor, d, in the payment of end-user.

***Definition* 4.** *Discount factor is received by the end-user from the Safe-aaS infrastructure, if the end-user requests information beyond a time instant, t', such that $t_{use} > t'$.*

SSP is the centralized governing body, which administers the entire maintenance and financial issues along with registrations of the other active components of Safe-aaS. The net profit of any i^{th} SSP, SP_i, is denoted as:

$$P_{SP_i} = \sum_{i=1}^{z} (C^i_{tmpc} t_{use} - C_{pn} \frac{(t_{rcv} - t_{allw})}{60}) \quad (17)$$

where P_{SP_i} is the profit of SP_i for z end-users, where z is the number of end-users registered to the safety service provider, SP_i, where $z \subset n$.

IV. Performance Evaluation

A. Simulation Design

To evaluate the performance of the proposed infrastructure, we consider total 100–$1,000$ sensor nodes over a simulation area of $10km \times 10km$. We consider the presence of 5 types of static, inbuilt and externally placed sensor nodes, which belong to 5 type of sensor owners. The owners of sensor nodes are categorized as sensor-owner, active vehicle owner and passive vehicle owner. The simulation parameters we consider are listed in Table I.

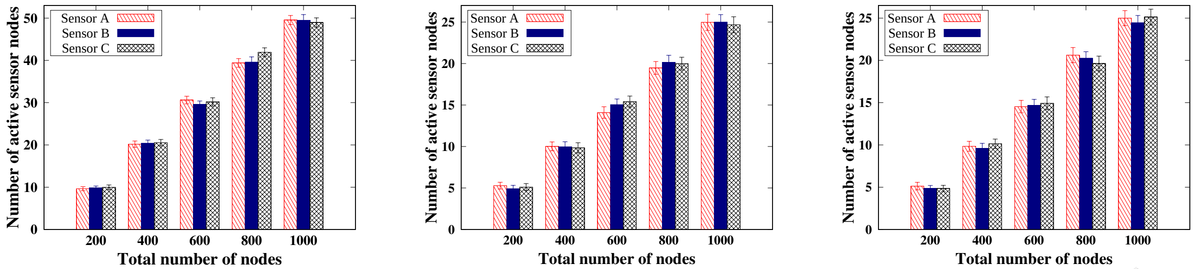
TABLE I: Simulation Parameters

Parameter	**Value**
Communication range	30 – $80m$
C_{S_i}	75 units
C_{deploy}	25 units
$C_{variable}$	30 units
C_{tmpc}	100 units
C_{pn}	15 units
Discount factor (d)	5%

B. Results

We evaluated the proposed architecture of Safe-aaS using the following performance metrics:

Number of active sensor nodes: In Figs. 3(a)-3(c), we consider the presence of static, externally placed, and inbuilt sensor nodes with sensor types A, B, and C out of the 5 sensor



(a) Static sensor nodes (b) Externally placed sensor nodes (c) Inbuilt sensor nodes

Fig. 3: Variation of active sensor nodes in the scenario

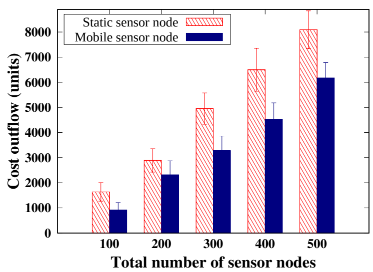


Fig. 4: Cost outflow of sensor/vehicle owners

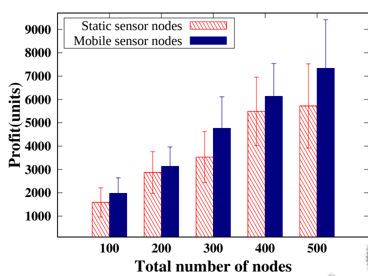


Fig. 5: Profit of sensor/vehicle owners

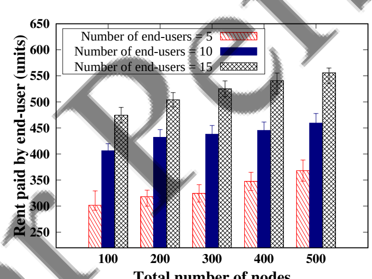


Fig. 6: Rent paid by end-users

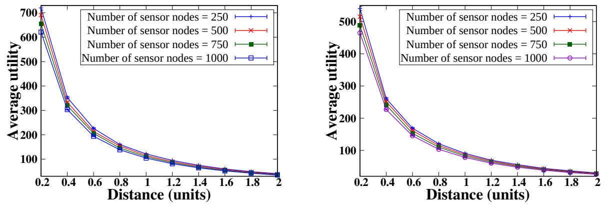
nodes considered in the simulation. The total number of nodes in the network varies (along the x-axis) from 200–1000 with an interval of 200. We observe an increasing trend in the number of node activations with the increasing total number of nodes present in the system. Interestingly, we observe that the number of active nodes is always higher in the case of static sensor nodes, as compared to the externally placed and inbuilt ones. The possible reason for this trend of increasing number of static sensor nodes is that the externally placed and inbuilt sensor nodes are activated only when the vehicle is mobile. Therefore, these nodes sense and transmit data when they are mobile. On the other hand, static sensor nodes are activated for monitoring some physical phenomena continuously.

Cost outflow of sensor/vehicle owners: Fig. 4 represents the cost outflow of sensor/vehicle owners, considering the presence of 100 – 500 sensor nodes in the system. We increase the total number of nodes in the network in steps of 100 for both static and mobile sensor nodes. In each case, we observe that the cost outflow increases with an increase in the total number of nodes in the network. However, we notice that the cost for static sensor nodes is always greater than the same for mobile sensor nodes. The mobile sensor nodes are not always activated due to their dynamic mobility, whereas the static sensor nodes are active during the maximum duration of time. Thus, the variable cost associated with the externally placed mobile sensor nodes is lesser as compared to static sensor nodes. Consequently, the total cost in static sensor nodes is more than the same for mobile sensor nodes.

Profit of sensor/vehicle owners: Fig. 5 shows the profit incurred by sensor/vehicle owners for providing the services in Safe-aaS. The x-axis of the figure depicts the presence of total number of sensor nodes in the network starting with 100 and increasing up to 500, in steps of 100. In this figure, we observe the increasing trend in profit with the increase in the total number of nodes in the network, for both mobile and static sensor nodes. One of the possible reasons for this type of trend is – the active vehicle owner have inbuilt sensor nodes, so they do not pay the fixed cost always. Consequently, the mobile sensor owners acquire more profit compared to the static sensor owners.

Average payable rent by end-users: In order to examine the average payable rent by an end-user, we consider the presence of 5, 10, and 15 end-users respectively. Fig. 6 depicts the change in the average payable rent by the end-users when the total number of nodes varies from 100–500. From the figure, we observe an obvious increasing trend in rent with the increase in the number of end-users. However, we also observe that if the total number of nodes present in the network increases, the average payable rent increases accordingly. The possible reason for this trend is that when the number of nodes is 500, the end-users are served with more number of nodes as compared to the presence of 100 nodes in the network.

Utility of sensor nodes: Fig. 7(a) and 7(b) depict the utility of the static and mobile nodes. The vehicles are mobile, so, the distance between the mobile node and the edge node



(a) Static sensor nodes (b) Mobile sensor nodes

Fig. 7: Variation of average utility with distance

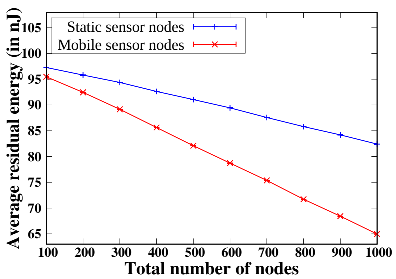


Fig. 8: Residual energy of sensor nodes

varies. In this plot, we consider the distance between the edge node and static/mobile nodes along the x-axis. We observe that there exists an increasing trend in utility of the sensor nodes with increasing distance. We infer from these plots that the possibility of choosing a sensor node is more when the distance between sensor node and the edge node reduces.

Analysis of residual energy: Fig. 8 shows the comparison of residual energy in case of static and mobile sensor nodes with the variation in the total nodes from 100-$1,000$. For both static and mobile type sensor nodes, the residual energy decreases with the increase in the total number of nodes present in the network. However, the rate of decrease in residual energy is more in case of static sensors compared to that of mobile sensors. The static sensor nodes are fixed at certain geographical locations for continuous monitoring of certain parameters, which is the probable cause for steeper decreasing trend of residual energy.

C. Application-specific case studies

The main objective of Safe-aaS infrastructure is to provide road safety related decisions to end-users. We discuss two case studies in order to show the applicability of Safe-aaS in real-life.

Case Study I: Road safety service

Mr. X plans for a hill station trip, B, by his own car. The current location of Mr. X is A. His car is equipped with multiple sensor nodes, which has the capability to provide several safety related data, such as air pressure, camera, and temperature. Mr. X has no idea about the road conditions (including turns, number of speed breaker, pot hole). Thus, Mr. X registers himself with Safe-aaS infrastructure by providing a source as A and destination as B. He selects the decision parameters *weather*, *turns*, *the number of speed breakers*, and *pot holes*. On the other hand, another end-user, Mr. Y, has logistic business. He wants to send some important goods by his heavy vehicle, from location A to B. The driver of the heavy vehicle is new to the road between locations A and B. Therefore, in order to send the goods quickly and safely, the owner of the heavy vehicle, Mr. Y, registers himself with the same Safe-aaS infrastructure as Mr. X. At the time of registration, the decision parameters chosen by Mr. Y are – maximum permissible weight, congestion, and weather. Considering the given scenario, Mr. X and Mr. Y both start their journey. For the first p kilometers (km), both vehicles travel through the same road. However, at $(p + \delta p)$ km, the inbuilt sensor nodes of Mr. X's vehicle sense the data from the camera equipped in the vehicle and transmit those to the nearest edge node. Further, the edge nodes process the data and find that the road is congested after p km from the starting point, A. On the other hand, the edge nodes receive data from static sensor nodes placed on the road. As shown in Fig. 9, the edge nodes process these data and determines that there is congestion up to the next q km from p. Additionally, another set of sensors report that there is a road slide at the $(p + \delta p')^{th}$ km from the starting point and a huge number of heavy vehicles are stuck. However, there is another bypass road between p and q. Thus, the decision is virtualized and provided to the driver of the heavy vehicle to choose the bypass road, so that the congestion can be avoided.

Case Study II: Patient transit

Consider the same scenario as mentioned in Case Study I. In the given scenario, an ambulance is started from a small hospital at location B for transiting a patient to a multi-specialty hospital at location C, far away from A. However, among the three roads to reach location C from location B, there is a congestion on the shortest road between A and B. In such a situation, the heavy vehicle of owner Y (in Case Study I) transmits the sensor data to its nearest edge device. On processing the data received from the heavy vehicle, it is observed that there is significantly less number of vehicles on the road. Consequently, the decision is virtualized and the driver of the ambulance is instructed to take the bypass road in order to reach faster.

V. Conclusion

In this paper, we have proposed the mathematical model of SOA-based Safety-as-a-Service infrastructure (Safe-aaS). This architecture provides safety related decisions to multiple end-users at the same time instant using decision virtualization. As per our knowledge, this is the first attempt in the direction of road transportation, where customized safety decisions are provided dynamically on end-user demand. Additionally, we show the two case studies, which depict the real-life applicabilities of Safe-aaS.

Different research problems are needed to be solved in Safe-aaS for its real-life implementation for use in the road transportation industries. However, in future we plan to explore the problems in Safe-aaS, considering different technical and implementation related aspects in its different layers. In practical scenario, there are chances of the presence of selfish, malicious, and misbehaving nodes in Safe-aaS architecture, which we will consider in future and thereby, provide the solution to tackle these nodes. Additionally, we target to work on the pricing model for different actors in the Safe-aaS architecture, by utilizing the reputation of the sensor nodes. In the presence of different entities involved in Safe-aaS architecture, such as SSP, vehicle owner, and end-users, the security and privacy are required to be considered. We plan to extend our work by considering the security and privacy issues in Safe-aaS.

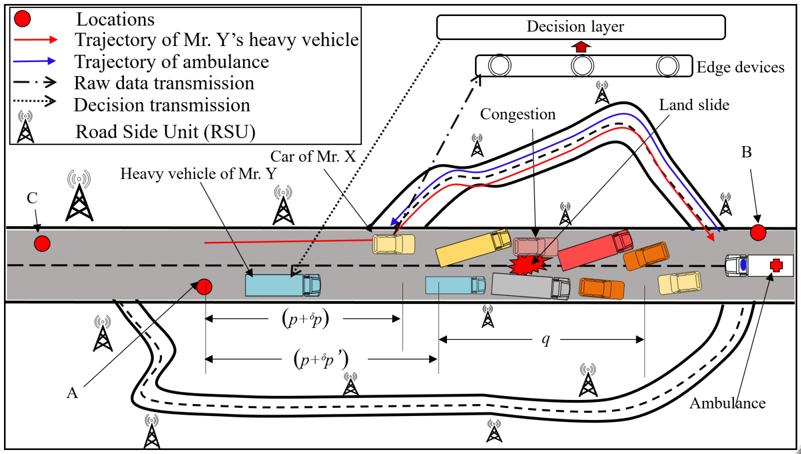


Fig. 9: Case Studies: (I) Road Safety Service, and (II) Patient Transit

References

[1] C. Perera, C. H. Liu, and S. Jayawardena, "The Emerging Internet of Things Marketplace From an Industrial Perspective: A Survey," *IEEE Transactions on Emerging Topics in Computing*, vol. 3, no. 4, pp. 585–598, Dec 2015.

[2] L. Catarinucci, D. de Donno, L. Mainetti, L. Palano, L. Patrono, M. L. Stefanizzi, and L. Tarricone, "An IoT-Aware Architecture for Smart Healthcare Systems," *IEEE Internet of Things Journal*, vol. 2, no. 6, pp. 515–526, Dec 2015.

[3] N. Kumar, J. J. P. C. Rodrigues, and N. Chilamkurti, "Bayesian Coalition Game as-a-Service for Content Distribution in Internet of Vehicles," *IEEE Internet of Things Journal*, vol. 1, no. 6, pp. 544–555, Dec 2014.

[4] I. Kalamaras, A. Zamichos, A. Salamanis, A. Drosou, D. D. Kehagias, G. Margaritis, S. Papadopoulos, and D. Tzovaras, "An Interactive Visual Analytics Platform for Smart Intelligent Transportation Systems Management," *IEEE Transactions on Intelligent Transportation Systems*, vol. PP, no. 99, pp. 1–10, 2017.

[5] M. Louta, K. Mpanti, G. Karetsos, and T. Lagkas, "Mobile crowd sensing architectural frameworks: A comprehensive survey," in *the 7^{th} International Conference on Information, Intelligence, Systems Applications (IISA) 2016*, July 2016, pp. 1–7.

[6] S. Glaser, B. Vanholme, S. Mammar, D. Gruyer, and L. Nouveliere, "Maneuver-Based Trajectory Planning for Highly Autonomous Vehicles on Real Road With Traffic and Driver Interaction," *IEEE Transactions on Intelligent Transportation Systems*, vol. 11, no. 3, pp. 589–606, Sept 2010.

[7] D. Song, R. Tharmarasa, T. Kirubarajan, and X. N. Fernando, "Multi-Vehicle Tracking With Road Maps and Car-Following Models," *IEEE Transactions on Intelligent Transportation Systems*, vol. PP, no. 99, pp. 1–12, 2017.

[8] I. I. Sirmatel and N. Geroliminis, "Economic Model Predictive Control of Large-Scale Urban Road Networks via Perimeter Control and Regional Route Guidance," *IEEE Transactions on Intelligent Transportation Systems*, vol. PP, no. 99, pp. 1–10, 2017.

[9] C. Tsotskas and M. Louta, "Investigating the application of multi-objective optimisation and multi-criteria decision making to future concepts of intelligent mobility and telecommunications," in *the 7^{th} International Conference on Information, Intelligence, Systems Applications (IISA) 2016*, July 2016, pp. 1–6.

[10] D. Calabuig, D. Martin-Sacristan, J. F. Monserrat, M. Botsov, and D. GozÃąlvez, "Distribution of Road Hazard Warning Messages to Distant Vehicles in Intelligent Transport Systems," *IEEE Transactions on Intelligent Transportation Systems*, vol. PP, no. 99, pp. 1–14, 2017.

[11] N. Nikookaran, G. Karakostas, and T. D. Todd, "Combining Capital and Operating Expenditure Costs in Vehicular Roadside Unit Placement," *IEEE Transactions on Vehicular Technology*, vol. 66, no. 8, pp. 7317–7331, Aug 2017.

[12] M. Fazeen, B. Gozick, R. Dantu, M. Bhukhiya, and M. C. González, "Safe driving using mobile phones," *IEEE Transactions on Intelligent Transportation Systems*, vol. 13, no. 3, pp. 1462–1468, 2012.

[13] E. Bertolazzi, F. Biral, M. D. Lio, A. Saroldi, and F. Tango, "Supporting Drivers in Keeping Safe Speed and Safe Distance: The SASPENCE Subproject Within the European Framework Programme 6 Integrating Project PReVENT," *IEEE Transactions on Intelligent Transportation Systems*, vol. 11, no. 3, pp. 525–538, Sept 2010.

[14] A. Amditis, E. Bertolazzi, M. Bimpas, F. Biral, P. Bosetti, M. D. Lio, L. Danielsson, A. Gallione, H. Lind, A. Saroldi, and A. Sjogren, "A Holistic Approach to the Integration of Safety Applications: The INSAFES Subproject Within the European Framework Programme 6 Integrating Project PReVENT," *IEEE Transactions on Intelligent Transportation Systems*, vol. 11, no. 3, pp. 554–566, Sept 2010.

[15] R. C. Luo, C. C. Yih, and K. L. Su, "Multisensor fusion and integration: approaches, applications, and future research directions," *IEEE Sensors Journal*, vol. 2, no. 2, pp. 107–119, Apr 2002.

[16] M. Louta, S. Kraounakis, and A. Michalas, "A survey on reputation-based cooperation enforcement schemes in wireless ad hoc networks," in *International Conference on Wireless Information Networks and Systems (WINSYS) 2010*, July 2010, pp. 1–4.

[17] N. Mantas, M. Louta, E. Karapistoli, G. T. Karetsos, S. Kraounakis, and M. S. Obaidat, "Towards an incentive-compatible, reputation-based framework for stimulating cooperation in opportunistic networks: a survey," *IET Networks*, 2017.

[18] S. Kraounakis, I. N. Demetropoulos, A. Michalas, M. S. Obaidat, P. G. Sarigiannidis, and M. D. Louta, "A Robust Reputation-Based Computational Model for Trust Establishment in Pervasive Systems," *IEEE Systems Journal*, vol. 9, no. 3, pp. 878–891, Sept 2015.