VLC Enabled Foglets Assisted Road Asset Reporting

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***Abstract*—There has been a lot of work on emergency reporting in smart transportation system, but we find very less information about road sides assets reporting and management. Currently available mechanisms do not efficiently handle asset management and any emergency reporting. Asset management is based on either reactive maintenance reported by people or preventative scheduled maintenance. In this article, we present a reporting architecture for emergency situations and, management through Foglets and visible light communication (VLC). Foglet is the processing agent in Fog computing, a computing platform that provide services with improved QoS and reduced latency. VLC use the visible portion of the spectrum and has proved itself to be promising technology in terms of capability, capacity and safety as compared to conventional RF communication.**

Index Terms–Internet of Things, Foglets, VLC, Smart Vehicle, Road Side Asset Management

I. Introduction

With the recent advancement in research and implementations of Internet of Things (IoT) applications, demand of both data communication and computational capability of devices has increased. IoT supports various services ranging from the content-sharing applications (e.g., advertisements and entertainments) to the information-spreading services (e.g., emergency operations for natural disaster and terrorist attack. Several technological solutions based on WiFi/WIMAX are available to fulfill the demands of higher data rates in this regard. As a result the RF spectrum is getting scarcer by every passing day and there is push for more bandwidth exploration in alternative spectrum bands. Optical wireless communication (OWC) systems are getting noticeable attention from research community and industry, to tackle the RF spectrum limitations. In addition to this, it has numerous potential advantages, in particular, the usage of the freely available visible light spectrum. VLC is a category of OWC and known as green technology. It uses visible light wave length between 375 nm and 780 nm and is a powerful alternative to radio frequency (RF), specially, with the fast growing wireless data demand and the saturation of RF spectrum.

Current Intelligent transportation system research activities, products, and standardizations are mainly focused around the deployment of RF based communication technologies for wireless connectivity. However, VLC has recently emerged to become a promising wireless communication technology. It is a suitable candidate to complement conventional RF communication for indoor and outdoor medium and short range data transmission. It uses LEDs for data communications, illumination and localization. VLC has many advantages including low-cost front-ends, energy-efficient transmission, huge (THz) bandwidth, and no electromagnetic interference, beside, its safe for human and has no eye safety constraints like infrared. VLC has potential applications in a number of areas such as smart lighting, indoor localization, vehicles and transportation, underwater communication, and in many other fields. There are many research activities on the theoretical aspects and experimental investigation of VLC for outdoor applications such as: vehicle to vehicle, vehicle to infrastructure, and infrastructure to vehicle. In [1], authors studied the feasibility of a road-to-vehicle communication system using a LED array and a high-speed camera. Authors used hierarchical coding scheme to allocate data to different spatial frequency components depending on their priorities. In [2], an outdoor VLC system for the intelligent transportation system ITS application is investigated, where a direct sequence spread spectrum scheme replaced on-off keying (OOK) and/or pulse position modulation, to minimize the effect of ambient noise. In [3], the channel characterization of a traffic light to vehicle VLC system is studied, and analytical LOS path loss model is proposed. However, in many respects, this technology is in its beginning and requires further research efforts in several areas including channel modeling, physical layer design, and upper layer protocols.

High data rates of VLC systems require higher and faster computational devices and systems to provide real time coverage to large scale IoT applications. Fog computing is the new emerging distributed computing paradigm, which provides variable degrees of storage and computational services to devices at various network levels.

Fog computing have several advantages over the traditional cloud computing. It suits applications like video streaming, gaming, AR, etc. Fog computing framework is applied to implement the software defined networks concept for vehicular networks in [4]. It resolve the issues of connectivity, collisions, and high packet loss rate, by augmenting vehicle -to- vehicle and vehicle-to-infrastructure communications. Fog computing is also used to study adaptive traffic light control for smoothing vehicles' travel and maximizing the traffic throughout. It help fewer stops and more vehicles will pass through the intersection thus reducing CO2 emissions [5].

II. VLC Enabled Foglets

New applications, such as augmented reality (AR) techniques, self-driving, smart vehicles and transportation etc.; all deal with complex data processing and storing operations. It require higher level of data communication, computation, and storage capabilities. Communication capacity is of great significance in smart transportation infrastructure as information exchanges cannot happen without reliable communications. To deal with the higher level of data communication, VLC has proved itself to be a promising technique in terms of data rate and negligible electromagnetic interference. In order to deal with the computation and storage requirement, Fog computing is a promising computing platform [6]. It is based on distributed computing and deployments in contrast to cloud; which is centralized. Since it is localized, it provides low-latency communication and more context awareness. **Objective:**We combine the best of two worlds to provide instant asset and incident reporting. We benefit from the high data rates of VLC and greater computational speed of Foglets to report for the hit and run cases and asset damage reporting. We use smart vehicles and employ them as infrastructure, and moving features of vehicles carry the information from one place to another place. Moving vehicles become good message carriers and can continuously transmit information by building up new connections with accessible Foglets. Instead of sending information to cloud servers, damage reporting tasks are completed by utilizing computational and communication resources locally inside Foglets. All these bring less delay, lower power and lower cost of operation.

A. Fog Computing

Fog computing is used to enable applications on billions of connected

devices, already connected in the Internet of Things (IoT), to run directly at the network edge [4]. Both cloud and fog provide data, compute, storage, and application services to end-users. The distinguishing fog characteristics are its proximity to end users, its dense geographical distribution, and its support for mobility in Fog networks (Fognets). The main characteristics of FogNet include ubiquity, de-centralized management and cooperation [7]. Large amount of devices are connected to Internet in these Fognets. These devices form many "mini clouds" at the edge of the network and manage themselves in a distributed way. FogNet, therefore, may significantly alleviate the computing and routing burdens in the cloud-part of networks to achieve the scalability. The users need not download the data from the core network, instead, they just download the required data from their neighbors, and hence reduction of end-to-end latency is obtained. The Fog vision is conceived to address applications and services that do not fit well in the paradigm of the Cloud [8]. It includes but not limited to:

- Applications that require very low and predictable latency such as gaming and video conferencing. Fog frees the user from precise knowledge of where the computation and storage takes place.
- Geo-distributed applications (pipeline monitoring, sensor networks to monitor the environment).
- Fast mobile applications (smart connected vehicle, connected rail).
- Large-scale distributed control systems (smart grid, connected rail, smart traffic light systems).

The fog computing paradigm is well positioned for real time big data analytic, supports densely distributed data collection points, and provides advantages in entertainment, advertising, personal computing and other applications. Fog computing based architectures can be roughly modeled by a simple three level hierarchy, where each smart thing is attached to one of fog devices, fog devices could be interconnected, and each of them is linked to the cloud.

B. Challenges and Motivation

To solve the communication and computational capacity problem for smart vehicles and latency sensitive application, existing methods include 3G and 4G cellular networks, road-side units (RSUs), and mobile cloud computing. However, these are not sufficient as cellular networks provide supportive communication but are controlled primarily by network operators, which is not efficient and effective from the application aspect. RSUs enlarge the network communication capacity but are expensive and are not applicable for delay sensitive applications. As high quality of network connections are required when uploading real-time information otherwise it will be time consuming to exchange information from remote servers. Mobile cloud computing can bring rich computational resources to mobile users but is costly and time consuming. Therefore, it remains a great challenge for researchers and engineers to deal with communication and computational demands efficiently and conveniently.

1) Foglets and Distributed Data Processing: Most of IoT applications and specifically our presented infrastructure requires processing closer to the road, and a tighter coupling between events and actions. We might introduce unnecessary latency and greater potential for network failure, by utilizing centralized cloud for events requiring immediate actions. We propose to bring computing and storage of network resources near the smart vehicles and roads. It will improve efficiency and reducing bandwidth requirement and latency , however, coordination between resources and devices for distributed processing is challenging.

2) Why VLC for Foglets: VLC technology has many essentials advantages over the RF based devoted short range communication technology, which could be adopted for ITS applications. Offering low complexity and a low cost, particularly in places where LED lamps are already installed in vehicles, traffic lights and street lights is considering as a first advantage, while high precision positioning, owing to the high directional LOS propagation characteristics be a second advantage. The VLC based positioning technology is able to reduce the positioning error to tens of centimetres, which is more accurate than the RF based positioning technology. One more advantage is the scalability, where the high scalability [9], as vehicle density increases, e.g. during rush hours, traditional RF will typically experience undesirable packet collisions and

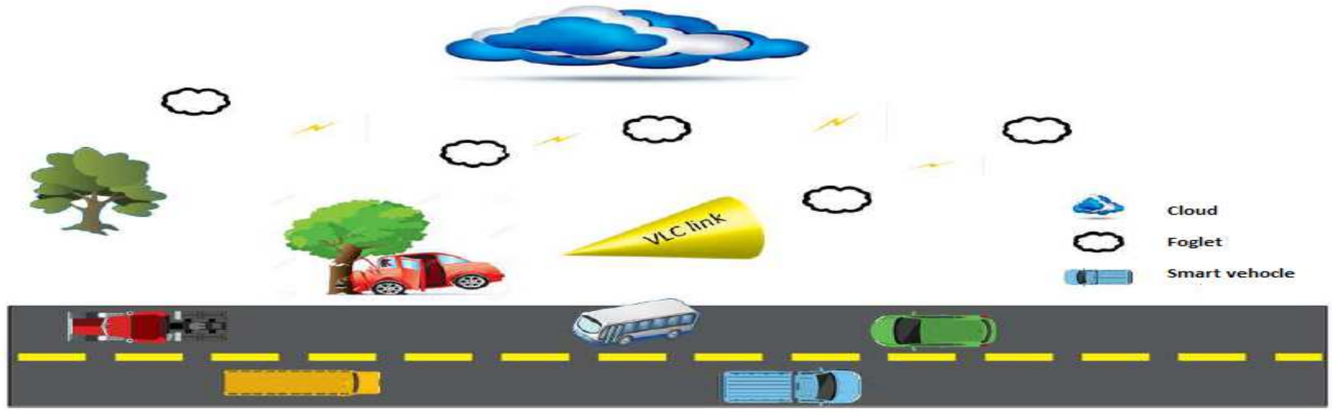

Fig. 1. VLC Assisted Asset Management Infrastructure.

longer delays as well as poor packet reception rate. However, integration of VLC technology with ITS faces two important challenges, the metrological issues like (rain, fog, dust, etc.) and the background noise which will be reflected on the maximum data rate Rb that can be transmitted.

3) Contributions: The main contribution of this article is to propose and present a reporting architecture for road assets using visible light communication and Foglets. We emphasize that how Fog computing will enable the road asset management and hazard reporting by utilizing the smart vehicles. It has wide application spectrum as it will support public security, infrastructure management and emergency medical aid. We can list our major contributions as under:

- An road cosmetics safety infrastructure is presented, in which two tier connectivity is proposed among various nodes. VLC is used for communication between smart devices and Foglets in the first tier and cellular/LTE is used between Foglets and back end data base in second tier.
- Smart moving vehicles having unique ID are used as a part of proposed infrastructure, reporting the incidents like hit and run cases. These moving vehicles will be communicating information with more than one Foglets on their way to destination. Until desired action is taken and this vehicle is given an ACK signal for reception of the information.
- Road side assets and cosmetics is reported instantly to concerned authorities and required action is taken immediately.
- We have modelled the VLC link between vehicle and Foglets by considering the LOS and reflected paths. Luminosity and BER characteristics are studied as a function of distance between vehicle and Foglet.

III. Road Asset Management and Incident Reporting

We propose road asset reporting with the help of smart vehicles and Foglets as shown in Figure 1. Foglets are true enabler for services requires low latency such as connected vehicles and accident reporting. Smart vehicles will interact with roadside Foglets and also with other smart vehicles. As these vehicles are smart vehicles, we assume that they have unique identification or IP address. Communication link between smart vehicles and Foglets is VLC. Head lamps and tail lamps are used as transmitters for information transfer, while camera in Foglets are the receivers of this transmitted information. Vehicle lights have started to utilize LEDs and due to their shorter response time, they can be easily modified to become VLC transmitters.

We have the following goals to be achieved:

- Accident reporting and hit and run cars identifications.
- Maintenance and incident reporting of road side asset like traffic lights, water reservoir, trees etc.
- Collection of relevant data to evaluate and improve the system.

We want to divide theses tasks between Foglet and centralized cloud. Tasks which are not handled well by Fogs are assigned to clouds.

A. Infrastructure

Proposed infrastructure is shown in Figure 1. We require Foglets to be installed at roadside at certain distances. We are not investigating the placement of these Foglets rather we assume that these optimally placed and serve the wide area under observation. We suggest their placement at barren places where there is no other reporting mechanism for potential disaster. We have smart vehicles which can communicate with Foglets and which in turns are in communication with centralized cloud. These Foglets are also in communication with each other thus creating an interconnected network of distributed nodes.

B. Smart Vehicle

Smart vehicles, through their advanced communication capabilities, are able to interact not only with navigation and broadcast satellites, but also with passenger smart phones, roadside units and other smart vehicles.

Fig. 2. Foglets Architecture.

C. Foglets Infrastructure

Detailed Foglet architecture is shown in Figure 2. Foglets are comprised of cameras with special optical sensors. These Foglets are connected to one another and to centralized cloud through cellular connectivity.

1) Rolling Shutter Cameras: Cameras have been used for safety and comfort applications in the automotive field [10]. Therefore, using the camera as the optical signal receiver is reasonable and straightforward. Moreover, the camera receiver provides the non-interference communication capability due to the excellent spatial separation capability of the image sensor mounted in the camera. Therefore, non crosstalk communication with multi-LEDs without a complicated protocol and processing is achieved by using a camera (image sensor). It also prevents optical signals from being mixed with noise (incident sunlight) and enables simple link designs.

Rolling shutter is a method of image acquisition in which each frame is recorded not from a snapshot obtained at a single point of time, but rather by scanning across either vertically or horizontally [11]. The transmitting LED light switches on and off at very high frequencies according to the modulation, and the pixels of the camera sensor activates sequentially (by row). Therefore does not get the entire image simultaneously. When the rows of pixels are activated, they are exposed to the light at that time and then their values are stored. After the procedure is completed, the scan lines captured at different time are merged together to form a single image.

2) Optical Communication Sensors: When we use cameras to capture images from vehicles, achieved data rate and accurate and quick LED detection are the main concerns. The data rates per pixel of typical camera receivers are in the tens of kb/s or less. However, for transmitting multi-media data from high speed vehicle, higher data rates such as few Mb/s/pixel are required. Additionally, the receiver system has to find the LED transmitters in captured images via image processing techniques. However, it is very hard to correctly and promptly detect LED transmitters from images under outdoor lighting environments with a low computing cost.

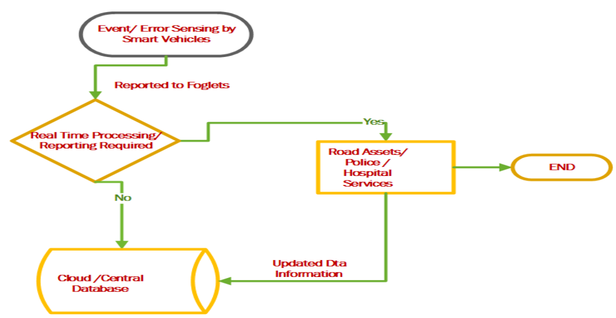

Fig. 3. Sequence of Foglets Tasks

Therefore, we purpose Optical communication image sensors [12] to be used in the cameras mounted in Foglets. These sensors has a non-conventional pixel, a communication pixel, which is specialized for high-speed optical signal reception. Additionally, it has an output circuit for a non-conventional image, which only reacts to high-intensity light sources such as LEDs and thus facilitates the LED detection. It is specially designed for receptions of high-speed optical signals. It provides substantially improved response speed to light intensity variations, and has 20 Mb/s optical signal reception per pixel.

3) Foglets Reporting: Traffic and hazard information from fog devices is forwarded to the cloud for global coordination. Fog devices are decision makers, and coordinate locally with neighboring fog devices and smart vehicles on the roads. If we elaborate further on our target goals (as listed earlier), we can see that all of them has different requirements in terms of time, processing and need. First goal of accident reporting and hit and run cases require real time processing. Second objective of Asset management requires real time reporting and also global analysis and management. Third objective relates to the collection and analysis of global data over long periods. We assign data accusation and processing of first two tasks to Foglets and third to cloud. Figure 3 show the sequence of tasks performed by our proposed system.

IV. Proposed VLC Channel between Vehicle and Foglets

In this section, suggested VLC channel is presented. In our model, we consider vehicle as a transmitter and the Foglet as a receiver for VLC link. We consider number of cars passing through the road and the road surface act as a reflector. These reflectors consider a lambertion reflectors, which mean, we can find the response of the reflector by treating it as a receiver when the signal is received from the transmitter and then as a transmitter when the signal is reflected to the receiver. Moreover, we consider a market-weighted vehicle's headlamps with lambertion source lighting pattern [13]. Background light noise interference exhibits a major limitation in the high speed rate data transmission in a VLC system. Because at the receiver side, PD is exposed to both required optical signals and the other natural/artificial illumination that is treated as unwanted optical noise interference. optical wireless channel involved noise can be modelled as [14]

$$Y(t) = \gamma\, X(t) \otimes h(t) + n(t) \quad (1)$$

where $X(t)$ denotes the transmitted signal and $Y(t)$ represents the received signals, respectively, γ denotes the conversion efficiency between optical and electrical signals,$h(t)$ denotes the channel impulse response, $\otimes$ means convolution and $n(t)$ denotes the Gaussian noise. In our model, there are two paths for the light, LOS which the direct path between the head and Foglet station and the non line of sight path (NLOS) which is the path between head and Foglet station through the reflector. The channels direct current gain of LOS is given [14]

$$H_{LOS}(0) = \frac{m+1}{2\pi d^2}\, A\, cos^m \phi\, cos\Psi \quad (2)$$

where d is the transmission distance, A is the exposure area of PD, ϕ and Ψ are the illuminance angle and the incidence angle, respectively. m is an order corresponding to the transmitter semi-angle $\phi_{1/2}$ (at half illuminance).

The NLOS path transfer function through any reflector is given by:

$$H_{NLOS}(0) = \frac{m+1}{2\pi d_1^2 d_2^2} \int_s A\, \rho\, cos^m \phi\, cos\alpha\, cos\beta\, cos\psi\, dA_s \quad (3)$$

where where d_1 is the transmission path from the vehicle light to a reflective point, d_2 is the transfer distance from the reflective point to the Foglet, dA_s is a reflecting surface element, ρ is the surface reflectivity, α is the incidence angle to the reflective point, β is the irradiance angle to the receiver.

A. BER of VLC Link

To study the performance of our proposed system, we need to find the BER and inturns the noise power. The shot noise induced by the solar radiation remains the main source of noise for VLC links during the daytime, as the artificial light induced interference has lower intensity than the solar radiation. However, the interference due to the artificial lights is the dominant noise source during the night time [3]. In our proposed system, we assumed OOK modulation and a Gaussian noise having a total variance that is the sum of contributions from the shot noise and thermal noise association with the receiver.

It is important to note, the typical channel delay for a VLC link is 10 ns compared to few MHz bandwidth used in a VLC system. Therefore, ISI introduced by the multipath environment is negligible [15].

B. Results and discussion

We used Matlab software and realize parameters to do the simulation for our suggested system. In Figure 4, the isocandela and isoilluminance diagrams of the road surface from a pair of high-beam headlamps with luminous intensities at the 75th percentile, are shown. It is apparent that for high beam headlamps, a narrow and flat beam is projected in a horizontal direction a few degrees to the left, providing a symmetrical illumination pattern on the road. However, the high-beam headlamps provide a symmetrical pattern designed to offer adequate forward and lateral illumination. This way, we can find a proper position to locate the Foglet station to be within the head light boundaries.

In Figure 5 total received power is plotted versus the communication distance between Foglets and head/tail lamps. Also, we plot the LOS path power in addition to, the NLOS path power. It is evident that, the dominant path in the VLC system is the LOS. Also, from Figure 4 and Figure 5, we notice that the good distance for communication between the vehicle and the Foglet station is up to 80-100 m when using the low-beam headlamps and about 120-150 m when using high-beam headlamp, where the illuminance will be about 1000(cd)

Figure 6 shows the BER for our proposed VLC link as a function of distance between Foglets and head/taillamps. It is evident that as the distance increases the BER is decreased which help in design the distance between the transmitter and receiver.

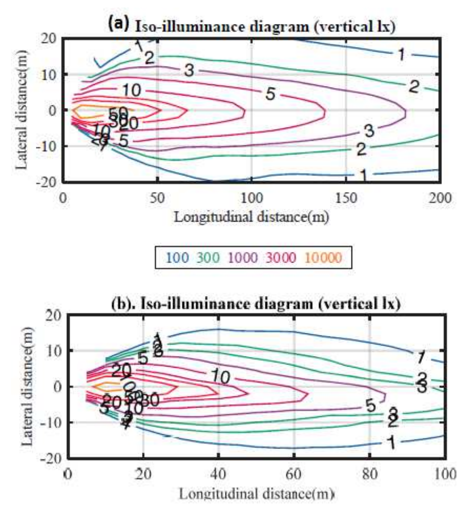

Fig. 4. Isocandela diagrams of the road surface from a pair of low beam and high beam headlamp.

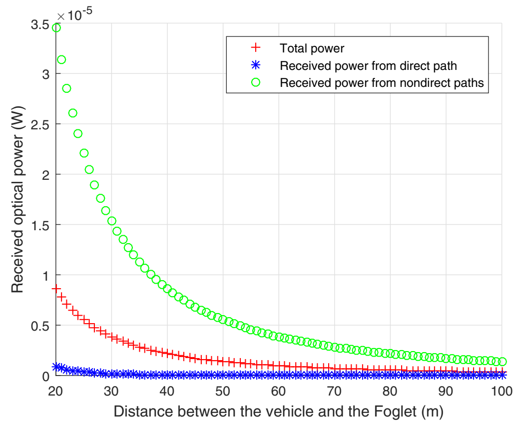

Fig. 5. Received power vs the distance between the vehicle and the Foglet station.

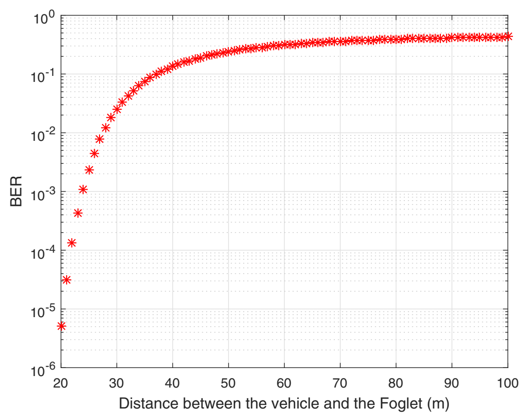

Fig. 6. The BER vs the distance between the vehicle and the Foglet station

V. Concluding Remarks

Fog computing save bandwidth as data is processed at the edge of the network; i.e., road side Foglets in our scenario. We promote distributed architecture for error reporting operations thus achieving fault tolerance, reliability and scalability of the system. We proposed an infrastructure of road side asset management by using Foglets and suggest a VLC link between smart vehicles and Foglets. Channel is modelled between head/tail lamps of vehicle and Foglet by considering LOS and NLOS paths and road as a reflector. Total received optical power from LOS and NLOS is calculated for different distances between the vehicle and the Foglet. The results show that the dominant contribution come from LOS path. For our future work, we aim to consider different categories of road surfaces, temperature and weather conditions as well as effects of multipath interference for high data rate systems. Also, we will consider ambient noise characteristics and effects of dust accumulation on headlamp and PD surfaces. In addition to this, we will do the comparative analysis between RF and VLC link between smart vehicle and Foglets.

References

[1] S. Arai and et al., "Feasible study of road-to-vehicle communication system using led array and high-speed camera," in *in 15th World Congress on Intelligent Transport Systems and ITS America's 2008 Annual Meeting, New York, USA*, 2008.

[2] N. Loureno and et al., "Visible light communication system for outdoor applications," in *Communication Systems, Networks Digital Signal Processing (CSNDSP), 2012 8th International Symposium on*, pp. 1–6, July 2012.

[3] C. Hongsong and Z. Dongyan, "Security and Trust Research in M2M System," *IEEE Vehicular Technology Conference*, pp. 286–290, Janauary 2011.

[4] I. Stojmenovic, "Fog computing: A cloud to the ground support for smart things and machine-to-machine networks," *IEEE Conference on Australasian Telecommunication Networks and Applications*, pp. 117–122, November 2014.

[5] S. Sarkar, S. Chatterjee, and S. Misra, "Assessment of the Suitability of Fog Computing in the Context of Internet of Things ," *IEEE Transaction on Cloud Computing*, vol. pp, pp. 1– 14, October 2015.

[6] A. Al-Fuqaha and et al., "Internet of Things: A Survey on Enabling Technologies, Protocols, and Applications," *IEEE Communications Surveys and Tutorials*, vol. 17, pp. 2347– 2376, November 2015.

[7] Hung.et.al, "Architecture Harmonization Between Cloud Radio Access Networks and Fog Networks," *IEEE Translations on Emerging Cloud-Based Wireless Communications and Networks*, vol. 3, pp. 3013–3034, January 2015.

[8] F. Bonomi and et al., "Fog Computing: A Platform for Internet of Things and Analytics," *Springer; A Roadmap for Smart Environments, Studies in Computational Intelligence 546*, pp. 169– 186, 2015.

[9] W. Viriyasitavat and et al.

[10] T. Y. et al, "Image-sensor-based visible light communication for automotive applications," *IEEE Communication Magzine*, vol. 52, pp. 88–97, July 2014.

[11] I. Takai and M. Andoh, "Optical Vehicle-to-Vehicle Communication System Using LED Transmitter and Camera Receiver," *IEEE Photonic Journal*, vol. 6, pp. 1–14, October 2014.

[12] I. T. et al, "LED and CMOS image sensor based optical wireless communication system for automotive applications,," *IEEE Photonics Journal*, vol. 5, p. 6801418, October 2013.

[13] Paudel and et al., "Modelling of free space optical link for ground-to-train communications using a gaussian source," *Optoelectronics, IET*, vol. 7, pp. 1–8, February 2013.

[14] J. B. J.M. Kahn, "Wireless infrared communications," *Proceeding of the IEEE*, vol. 85, pp. 265–298, Feb 1997.

[15] SeokJu Lee and et al., "Evaluation of visible light communication channel delay profiles for automotive applications," *EURASIP Journal on wireless communications and networkin*, pp. 1823–1826, 2012.