

## 1.1. Evolution of Traffic Signs

Traffic signs have been around for hundreds of years, since the invention of cars in the 1885 by Karl Benz. The first known traffic regulation act in Europe was established in 1686 by King Peter 11 of Portugal. The act governs the placement of priority signs in Lisbon, indicating which traffic should give way. By the 1900, a Congress of the International League of Touring Organizations in Paris was considering proposals for the standardization of road signage. In 1903, the UK government introduced four "national" signs based on shape. In 1909 [1], nine European governments agreed on the use of four pictorial symbols, indicating "bump", "curve", "intersection", and "grade-level railroad crossing". Traffic sign shapes were determined at the first Paris convention, with warning signs in the shape of triangles, regulator signs being round, and guide or informative signs being rectangular. The intensive work on international road signs between 1926 and 1949 eventually led to the development of the European road sign system. Both Britain and the United States had developed their own road signage systems. The UK adopted a version of the European road signs in 1964 and, over past decades, North American signage began using some symbols and graphics mixed in with English. Since 1945, most signs have been made from sheet aluminium with adhesive plastic coatings; these are normally retroreflective for night time and low-light visibility. Before the development of reflective plastics, reflectivity was provided by glass reflectors set into the lettering and symbols. In fact, past studies had examined the relationship between roadside signs and traffic accidents [2].

There are three motivations behind this research work: (a) poor and obstructed visibility of traffic signs, (b) challenges in positioning signs that are easy to be seen and spotted, and (c) difficulty in remembering all the highway code signs. These motivations are further discussed below.

## 1.2. Poor Visibility of Traffic Signs

The visibility of traffic signs is easily obstructed by trees, parked cars, and other objects located either in front or beside the signs. Also, bad weather such as heavy fog, rain, and snow can also obstruct visibility, rendering the sign less effective and even invisible to drivers. This has been a constant problem for drivers, and city authorities rely on road users to report issues on obstruction of traffic signs to them, so that the problem can be corrected.

## 1.3. Challenges in Placing Signs

The positioning of traffic signs [3] needs careful consideration and planning. They have to be positioned well ahead of the intended warning. For most people, signs are only visible at a certain close range. A driver too far away can fail to see the specifics of a sign. Also, its height, size, sign, and colour need to be effective for both day and night time. Cost of installation has to be paid by the city or by the department of transport. Installation of signs is labour intensive since the physical sign has to be transported and installed into concrete ground. Sign planning and distribution<sup>3</sup> are important aspects of

urban construction since they govern how many signs will be present in a road segment, and at intersections. In fact, there is a direct relation between the prese

## 1.4. Remembering the Highway Code

For driving safety, many transport authorities have enforced on the adherence of traffic signs by both drivers and pedestrians. Violations to traffic signs often have resulted in hefty traffic fines. Usually, ignoring a traffic sign, or simply stating that one did not see the traffic sign, is considered unacceptable to the traffic police. Drivers must pass the highway code test in order to be granted a driving license. Table 1 shows the numbers of road traffic signs that need to be studied, and it is no easy task to remember them all. Hence, for senior drivers (age 50 and above) and those with poor and fading memory, this can pose a problem.nce of traffic signs and road safety. Also, should regulation governing specific roads change, all signs on these roads may have to change as well, which is a labour intensive and slow process.

## 2. Technology Impact on Traffic Signs

There is a growing trend to employ wireless technologies on the roads. For example, toll collection has been automated with DSRC (Dedicated Short-Range Communications) technology [6]. There is also the emergence of V2V, V2I, and V2X technologies [7], with the purpose of enhancing road safety and making transportation infrastructure more intelligent. More recently,

autonomous self-driving vehicles [15][16] are attracting a lot of attention and investments from venture capitalists. The ability to drive on its own has found great attraction to transportation companies like Uber and Lyft, in addition to Google and Tesla.

## 2.1. Image Processing & Recognition .

The progress made on self-driving cars has been substantial in the areas of sensing and automatic control. Sensing has been enabled by LIDAR [8], generating maps of objects around the car in real-time, enabling the car to “see” who is around it, hence allowing the control logic within the car to navigate. In addition to LIDAR, some systems have employed multiple cameras and performed real-time video processing to guide car navigation. Also, there is a need to detect traffic signs, so that the car will obey and follow the guidance of the traffic signs. Chip makers understood the need for massive computation and high-speed signal and image processing for object recognition and have produced chipsets for this purpose. Examples are NVIDIA Drive-PX [9]. Traffic sign recognition [17] involves the use of camera-based systems to perform frame extraction from input video, colour-based segmentation, shape-based detection, and optical character recognition. Some systems also use machine learning [21] techniques (e.g. support vector machines) to eventually detect, classify, and identify the traffic sign. So, in addition to navigation, self-driving autonomous vehicles must be able to read traffic signs, and obey them when the vehicles are being driven on the roads

## 2.2. Sign Evolution with New Technology

If we look at the changes over the centuries, the earliest sign post can be considered as “analogue”, since it was a physical entity with a printed sign on its surface. The analogue version relies on drivers to see it and adhere to it. However, as mentioned earlier, obstacles and bad weather can obstruct the views of these signs, rendering them less effective. With the advent of LEDs [18] and digital sign boards [19-20], more such sign boards are used to warn drivers on the roads. The LED ones light up brightly both in the day and night to warn drivers, but they do not replace traffic signs. We can regard such digital LED sign boards as the second-generation traffic sign technology. Finally, as shown in Figure 1, the third-generation traffic sign is envisioned to be a digital sign post embedded with wireless electronics and software so that signs can be wirelessly transmitted to vehicles on the road. This smart traffic sign is programmable and fits well with the concept of Smart Cities.

## 3. Wireless Digital Traffic Sign Post

Traffic road signs have not changed nor have they been transformed significantly for hundreds of years. The current erect-and-display sign approach is seen to be analogue in the sense that it relies on drivers and pedestrians to see it and adhere to it. However, we had earlier discussed the visibility issues and obstruction problems associated with this approach. In the intelligent roads of the future, traffic road signs are supposed to be smart. The analogue traffic sign post can be made digital, and wirelessly enabled by using a digital client-server sign post architecture with a radio transceiver. By replacing the sign with a

Raspberry Pi [22] (or any programmable computing hardware) acting as a server, we can program such server to transmit a specific traffic sign wirelessly to on-coming cars on the road, as shown by Figures 2 and 3. Hence, multiple traffic sign servers can exist on a road segment. Signal directivity is important as signs are intended for on-coming vehicles to warn them well ahead in advance. Signs that a vehicle had driven past are no longer important since the drivers had already passed them. With signal directivity provided by directional antennas, signs can be directed at multiple on-coming vehicles, across all lanes in the direction of travel, as shown by Figure 2. Our proposed approach is different from the approach of installing RFID [23] tags on the roads and using such tags as traffic signs to be read by the RFID reader residing within a car. The disadvantages of RFID tags are their short communication range (about 40cm), and the need for a good reader-to-tag alignment accuracy [10].

Location information of digital wireless sign posts are also transmitted to on-coming cars, so that cars can compare their current locations relative to the sign posts to perform the appropriate reasoning and filtering out of signs. For example, if vehicles have already past the sign post, it is not necessary to display that sign information. Nowadays, most navigation systems used on cars have GPS already installed, and hence location information is readily available. For a 2-way street, cars on the other direction may receive wireless traffic sign transmissions from the opposite lane. Hence, detecting location and direction of travel is needed to filter out these irrelevant signs that are not intended for vehicles in the current lane and direction of travel. This can be done using intelligent logic in the car ADAS [11] or Heads-Up Display (HUD) [12] software to do the filtering.

Considering the current advances in signal processing and computation speed, this can be achieved at high speeds without losing important signs intended for the vehicles. Also, there is usually no more than 10 traffic signs on a road segment. With wireless transmissions from the wireless sign posts to vehicles on the roads, communication traffic load would still be manageable.

## 4. Wireless Digital Traffic Sign Architecture

As shown in Figure 3, the wireless digital traffic sign post architecture replaces existing physical traffic signs with posts embedded with electronics hardware and software. The hardware functions as a communication device and server. The traffic sign is then wirelessly transmitted to a client receiver residing in the vehicle. The client device is usually a smart phone or a car heads-up display. It can also be displayed on a car ADAS terminal.

### 4.1. Wireless Digital Traffic Sign Server

As shown in Figure 3, the server is a piece of computing hardware (example Raspberry Pi) that runs the necessary software program to transmit traffic signs wirelessly via WiFi 802.11g [27]. The server sends out periodic beacons, and also establishes link connections with clients (driver terminal or device). The server has to perform authentication to ensure clients are genuine, and that acknowledgements of the signs are made by the client. The acknowledgement confirms that the sign has been received, and it is expected that drivers adhere to the sign. The server runs an open source Linux Debian distribution, with a “hostapd” daemon. The “dnsmasq” application is used as a light-weight DHCP server. The “socketserver” provides reliable

transport, while the LWire.py is a python application used to service client information requests.

## 4.2. Wireless Digital Traffic Sign Client

Clients are devices or receiver units residing inside cars, and capable of receiving wireless traffic sign signals transmitted on the road. The client software application can be written as an Android application and can prompt a display of sign and voice output. It can also authenticate the validity of these sign signals, to ensure they are genuine. Effectively, the client establishes first an association, followed by security validation, data transfer, and close of connection. All these sign signal handshakes take place over a reliable transport connection. An implementation of a client on an Androidbased smartphone was completed and tested on the roads, with results on notification time, memory and computation requirements, and battery life, in addition to comparisons against other mobile applications implemented by Bosch, Evotegra, and Michelin [13].

## 4.3. Wireless Connectivity

In order to determine the appropriate type of wireless communication technology to use on the roads, one has to consider the distance of signal propagation, channel conditions, and physical parameters (such as obstacles, moving objects, etc.). Bluetooth is not a viable technology because of its short range, despite its low power feature. LORA [25] and SIGFOX [24] are suitable for lower power, long range sensor communications,



but are less suitable for the time-critical requirements of wireless sign posts. WiFi technology, on the other hand, provides longer radio transmission range, and has been used and experimented widely outdoors. WiFi uses the ISM unlicensed band at 2.4GHz, providing data throughput in the MBps range. Hence, given the popularity of WiFi, and the fact that it is readily and easily available on most off-the-shelf hardware, we propose the use of WiFi connectivity for wireless traffic sign architecture, and evaluated an implementation on the roads [13]. Using WiFi, the vehicle under test was alerted about the wireless sign well before approaching the wireless digital sign post, at distances ranging from 70 to 98 m on average, depending on the vehicular speed (see Figure 4). This distance would give the driver enough time to react. In the future, the wireless communications for WDSPs will be regulated (concerning operating frequency, minimum delay, SNR, security, signal power levels, etc.).

## 5. Communication Protocol & Software Stack

In a wireless traffic sign post architecture, a communication protocol is needed for signed data exchange between the client (device in the car) and the sign post (server). Protocol design considerations include timeliness, data integrity, authentication, and data exchange. As shown in Figure 5a, the server periodically transmits a beacon, identifying its presence. Upon receiving the beacon, the client performs authentication check procedures and, if successful, a link association is established between the client and server. Thereafter, a reliable transport (TCP) connection is established so that reliable data transfer can occur via REST-like data exchanges. The software components residing in the server and client are shown in Figure 6. The client side, which can be an

Android smartphone, uses the Android API to communicate with a specialized sign processing application. The “wpa\_supplicant” application handles the secure connection with different traffic signs (different servers). The client software will extract sign data and alert the driver (via both display and audio narration) so that he is informed about the sign. It can also send an acknowledgement (including vehicle ID number) back to the sign post to confirm receipt of the sign data. On the server side, the “hostapd” is a daemon program for IEEE 802.11g [27] access points management and WPA (Wi-Fi Protected Access) authentication services. WPA implements the IEEE 802.11i [26] standard, where a 128-bit encryption key is used and a message integrity code

## 6. Information Elements Exchanged

The beacon is a periodic broadcast signal for clients to scan for the presence of WDSPs. An example of its format is shown in Figure 7. The sign data transmitted to the client should contain the sign type itself, followed by the sign post ID, date, time, position information. A cyclic redundancy check (CRC) can be used to ensure integrity of the payload. Finally, the acknowledgement sent by the client back to server must contain the vehicle ID (such as VIN), the sign type acknowledged, date, time, and position information. It is also useful to transmit the vehicle current speed information back to the sign post, allowing

speed limit violations to be automatically detected in the future. This is a new area for future research.

## 7. Advantages of Wireless Digital Traffic Signs

This new architecture yields several advantages. Firstly, wireless transmission eliminates the need for the sign to be visible to the human eye and removes the load on the driver to watch out for signs while driving on the road, among many other things that the driver should watch out for. Secondly, it removes the burden on the driver to remember the meaning of all traffic signs since, with this architecture, the sign can be narrated via voice to inform the driver, in addition to displaying it on the dashboard or on a HUD. Thirdly, the WDSP is not affected by poor weather and lighting conditions, unlike existing traffic sign posts. Fourthly, the WDSP is programmable, and this means changing a sign is as easy as reprogramming it. This adds great feasibility and adaptability to changes in road situations and urban constructions. Fifthly, there is no need for complex signal processing and image recognition to recognize traffic signs in real-time, which is a computationally intensive activity, and not always accurate. Another advantage is the computation of traffic volume, since acknowledgements sent back by vehicles on the roads to WDSPs can be used to calculate the volume of traffic along the day. Next advantage is cost. The wireless digital sign post is relatively inexpensive to build and deploy. We have mentioned Raspberry Pi as an example, as it is a relatively cheap piece of hardware. We believe there are many other advantages awaiting to be realized.

## 8. Other Issues & Future Applications

In this section, we reveal additional new issues associated with wireless digital traffic signs that demand further research.

### 8.1. Spectrum

Currently, there are no ITU or FCC regulations or recommendations concerning what frequencies of wireless communications are to be used for wireless digital traffic signs, for both upstream and downstream transmissions. Telecommunication regulators will need to craft out a spectrum slot specifically for this purpose, so that transmissions over this frequency are regulated and signal interferences are minimized.

### 8.2. Power

Since wireless traffic signs need to be powered to support its operation 24x7x365, the server hardware must be powered by mains or batteries or through solar energy. Nonetheless, the existing power grids [29] in most cities are readily established and available in existing roads (for powering traffic lights) to power traffic signs, and hence extending power to traffic signs would not pose an issue.

### 8.3. Weather

The digital wireless sign post must work under all different weather conditions (hot sunny days, raining days, and cold winter nights)

## 8.4. Security

To avoid terrorists and hackers from creating havoc on the streets, traffic sign signals transmitted to cars must be authenticated and secured. Currently, there are no international standards governing wireless traffic signs signal exchanged, but this is likely to happen in the future, so that sufficient law enforcement and safety are in place for road users. This is an area for future research work.

## 8.5. Regulations on Hardware

Regulations and certifications regarding the transmitter (server) and receiver will need to be in place in the future. Future cars, through their ADAS [14] or navigation alert system, will tune in to the traffic sign signals, and reflect the signs directly to the driver via the dashboard or a display terminal within the car. Voice will be added to pre-warn the driver, in addition to signs displayed on the dashboard. Hence, it is likely that future cars will have preapproved electronic units to read signs off the road safely and reliably.

## 8.6. Future Traffic Violation Detection

Traditional methods of detecting traffic violations are done through pre-installed cameras and speed radar detectors [30]. These methods are less effective under rain, snow, and fog conditions. With the presence of wireless digital sign posts, new

traffic violation detection methods will be created. For examples, drivers will not be able to deny and ignore the presence of signs to traffic law enforcers, as the received and voice narrated signs will be recorded as evidence within the car ADAS client system. Hence, driving at a speed exceeding the stated speed limit will deem to have violated the traffic code, and law enforcers have a right to fine the driver. Similarly, refusing to stop at a stop sign will also be recorded as a violation. The changes here are that the wireless traffic signs received are recorded as proof of successful notification to the driver, and the driver cannot deny receiving it. Hence, WDSPs will help automate the handling of traffic violations in the future. This is a new topic that requires further research in the field of intelligent transportation systems for smart cities.

## 9. Conclusion

Road transportation has served our society well for several hundreds of years since its inception, and traffic road signs have been an indispensable part of it, assisting us in providing orderly traffic flows and reducing traffic accidents. However, with advances in wireless technologies and innovations in software, we envision that wireless digital sign posts, with advanced electronics and radio hardware embedded into poles, will be present to transmit designated or programmed traffic signs wirelessly on the roads. The wireless sign data will be received by drivers and be alerted of the sign. This intelligent form of wireless traffic sign architecture will ease the burden on drivers and enhance road safety. This architecture is one step forward towards realizing intelligent roads for future Smart Cities