

Smart Intersections – IoT insights using Wi-Fi



Challenge

- In Australia, overall road trauma continues to rise, with more incidents involving Vulnerable Road Users such as pedestrians and cyclists.
- Travel times in most cities continue to increase as roads become more congested.



Solution

- Leverage IoT Fog/Edge computing and Wi-Fi based analytics technology at roadside infrastructure to capture real-time lane level traffic flow and road user behaviour.
- Apply Wi-Fi based analytics to extract lane based queue length and intersection transition times.



Outcome

- Improved safety by identifying poor performing roadways and respond accordingly to improve traffic flow and intersection traffic.
- Create an accurate view of intersection safety rating and proactively apply relevant safety solutions.

Introduction

Globally, more than 1.25 million people die in road traffic crashes every year and a further 50 million people are injured or disabled.¹ Meanwhile, congestion costs Australians \$16.5 billion in 2015, according to the Bureau of Infrastructure, Transport and Regional Economics. The price of congestion is expected to double between \$27.7 and \$37.3 billion by 2030, without major policy changes.²

For the past few decades there has been a steady reliance on infrastructure improvements, safety campaigns, speed limit regulations, more stringent law enforcement to improve safety of our roads. Today, advances in technology such as IoT, Fog/Edge Computing, wireless sensors, Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) communications provide new powerful tools to tackle road safety, efficiency and sustainability.

Intersections represent a unique asset within a road transportation network and provide an opportunity for localised insights gathering through IoT technology (sensors and compute co-located inside road side infrastructure). For the first time we are able to piece together an accurate real-time picture of all road users, whether its vehicles, buses, cyclists, electric bike users or pedestrians at a lane level. As intersections become more intelligent and self-reliant, each tells its own unique story about performance, road user behaviour and risks without the need for any specialist equipment or applications in vehicles or other road users.

In this trial an Edge hosted Wi-Fi solution was evaluated for the purpose of extracting insights into road user behaviour and performance at the intersection within the AIMES testbed in Melbourne, in partnership with University of Melbourne, Department of Transport (DOT), Cohda Wireless, IAG and Cisco.

1. <https://www.who.int/en/news-room/fact-sheets/detail/road-traffic-injuries>

2. Bureau of Infrastructure, Transport and Regional Economics, Information Sheet 74: Traffic and congestion cost trends for Australian capital cities (2015).

Four use cases were conducted focusing on a number of road usage patterns to evaluate the capability and accuracy of the technology solution:

Use Case 1: Lane Level Traffic Flow (Vehicle Passing Rate):
Start-lane/end lane flow at intersections for individual vehicles.

Use Case 2: Lane Level Traffic Flow (Speed Histogram):
Detect average vehicle speed per lane at short (5 min);
Medium (15 min) and Long (Hour) duration.

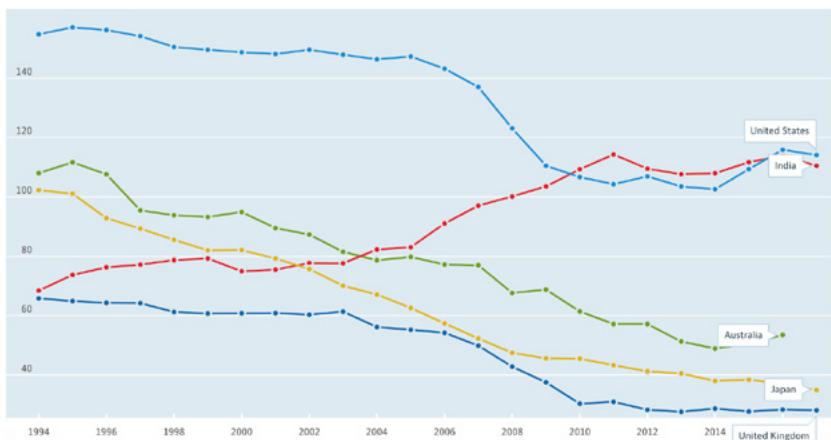
Use Case 3: Lane Level Traffic Flow (Stalled Detection Queue Length): Detect and report on queue length per lane.

Use Case 4: Pedestrian Traffic flow and Queue length.

The rising cost of road trauma

Australia has been among the countries with a better-than-average rate of fatalities to population and has been significantly improving from a rate above 100/million in 1990s to below 60/million in 2010s. However, after decades of improving, we are currently observing a change in trends. The number of road deaths recorded in Australia and the fatality rate to population has begun to rise since 2013.

Figure 1: Road Fatality Rates per Million Residents (Source: www.oecd.org)



According to the most recent data from BITRE there are around 100 road deaths per month in Australia and a third of these are pedestrians, motorcyclists and cyclists. Furthermore, for every fatal accident there are 30 others that require hospitalisation and nearly 6 times more non-hospitalised injuries.³ Between 2001 and 2016, there has been an increase of 29% in hospitalised injuries from road crashes.⁴

Aside from the obvious and personal impact of road trauma on individuals, families and the society, there is also an economic cost estimated at about 30 billion⁵ per year associated with our roadway trauma.⁶ It is imperative for us to understand the cause of this recent change in trends and to identify possible technology solutions to reverse it.

Planning authorities and road operators are under growing pressure to find solutions that address the safety and operational efficiency of our transport corridors without the ready ability to “build more roads”, or readily add more lanes, as the existing real estate has all been consumed. It is no longer viable or sustainable to rely on static and/or historic data. The advent of IoT, Edge computing, AI and other technologies provides us the ability to work smarter, offering new methods to capture what’s happening on our roads and subsequently plan for, and directly address these transportation challenges.

Keeping the traffic (and transport network) flowing

Australia’s capital cities have recorded a staggering population growth in the last few decades. More people in cities means more urban development, and since our population is growing at such a rapid rate, our infrastructure is constantly playing catch up with the extra number of cars on the roads.

Besides costing drivers’ hours of lost time in traffic and litres of wasted fuel, congestion cost Australians \$16.5 billion in 2015, according to the Bureau of Infrastructure, Transport and Regional Economics. The price of congestion is expected to double between \$27.7 and \$37.3 billion by 2030, without major policy changes.⁷ The government has already committed to a \$1 billion Urban Congestion Fund from the 2018 federal budget.⁸

Traffic congestion is also hurting businesses, with more than \$3.37 billion lost in wasted labour across Australia’s biggest cities, according to a Cost of Congestion report by TomTom Telematics. Extending the time spent on roads by an average of 27 minutes per day across Australia’s major metros is costing businesses an average of \$8.20 per vehicle each day.⁹ According to Australian Logistics Council, an increase in logistics total factor productivity of 1% is estimated to increase GDP by \$2 billion.⁹

Table 1: BITRE fatal accident data for the 12 months ending July 2019¹⁰

Year	Driver	Passenger	Pedestrian	Motorcyclist	Pedal Cyclist	Total
2015	555	251	161	203	31	1,204
2016	623	208	182	249	29	1,293
2017	567	255	161	211	39	1,223
2018	525	205	176	191	34	1,137
2019	571	223	176	208	31	1,214

3. https://www.aaa.asn.au/wp-content/uploads/2018/03/AAA-ECON_Cost-of-road-trauma-summary-report_Sep-2017.pdf

4. Hospitalised Injury, BITRE. <https://www.bitre.gov.au/publications/ongoing/hospitalised-injury.aspx>

5. These are estimates of the total social costs for 2015 and 2016 consisting property damage costs, fatality costs and injury cost.

6. Litchfield, F., 2016. The cost of road crashes in Australia 2016: an overview of safety strategies. The Australian National University.

7. Bureau of Infrastructure, Transport and Regional Economics, Information Sheet 74: Traffic and congestion cost trends for Australian capital cities (2015).

8. <https://www.aaa.asn.au/wp-content/uploads/2018/10/AAA-Congestion-Report-2018-FINAL.pdf>

9. <http://austlogistics.com.au/wp-content/uploads/2014/07/Economic-Significance-of-the-Australian-Logistics-Industry-FINAL.pdf>

10. Australian Road Deaths Database, BITRE. https://www.bitre.gov.au/statistics/safety/fatal_road_crash_database.aspx



Connecting the unconnected

While we tend to think of the Internet being everywhere, a staggering 99.8% of the world is still unconnected. Over the past decade a broad spectrum of organisations around the world embarked on the path of digitisation of the physical world. The Internet of Things (IoT) is the enabler for connecting physical and digital environments. We are extending connectivity to physical devices and objects (beyond computers, phones etc) for the purpose of extracting new data insights, making them smarter, interactive and self-aware.

IoT is all about Connecting the Unconnected. Whether counting people waiting at a bus stop or finding the nearest e-bike as part of Mobility-as-a-Service (MaaS), using sensors to assess rail track expansion on hot days or predicting failure of door controller on trains – “connectivity” is an enabler for data and subsequently new insights. In the context of mobility, connecting the unconnected – intersections, bus stops, stations, trains, trams – represents a huge opportunity to (a) improve safety and efficiency; (b) create new services and opportunities through insights and decisions.

Transport networks are under increasing pressure due to population growth, increasing urbanisation and expanding customer expectations. Combined with capacity constraints and increase in road trauma, it creates an urgency to look beyond traditional methods and tools. Can we adjust pedestrian crossing time when a large group of people are waiting to cross? Can we prioritise emergency vehicles and actively alert all road users? Can we more accurately identify high risk areas, where near misses occur? Advances in technology such as IoT, Edge computing, wireless sensors, vehicle-to-vehicle and vehicle-to-infrastructure communications make it possible to realise these solutions today. Capturing an accurate picture of what's happening at an intersection is the first step. Who are the road users? How do they interact and behave? Where are they?

Wi-Fi has been an integral part of our lives for many years and is the world's predominant wireless technology. Wi-Fi is everywhere and has a nearly 100 percent attach rate in smartphones and laptops¹¹ and is now starting to emerge in vehicles. This level of coverage and adoption opens doors for new applications. In this trial, the project is leveraging a Cohda Wireless Wi-Fi solution that taps into this technology to capture near real-time lane level location information of the road users and flow.

11. Next generation Wi-Fi®: The future of connectivity, Wi-Fi Alliance 2018.

Emergence of the Smart Intersection

With increasing popularity of new transport modes, including ride-hailing and ride-sharing services, electric and shared bike and scooter systems, urban transport is bearing a paradigm shift in roadway space utilisation. This is a positive transition to multimodal and sustainable use of transport resources; however, the shared use of roadway space introduces inevitable and new conflicts among modes and significant safety risks, traffic jams and delays to all road users. The transport infrastructure of the future should be capable of accommodating the multimodal travel demands efficiently and at the centre of it lies the smart intersection that ideally would be:

- **A safe intersection** where users from all modes can utilise the shared space and traverse without safety risks. In a connected transport system, vehicle-to-vehicle communication can help minimise risks of vehicle-to-vehicle collisions. Advanced sensing and communication technologies can help improve safety for vulnerable road users. Edge computing and IoT enabled interventions can be designed and deployed for this purpose. For example, warning messages can be sent to heavy vehicles when vulnerable road users are detected in black spots, or warning messages to drivers on collision course due to one vehicle appearing to be imminently running a red light, or blocking the intersection. Such interventions were previously tested in prior trials of AIMES.¹²
- **An efficient intersection** where optimal right-of-way is allocated to competing movements at the intersection. With the advent of real-time traffic counts by all modes, optimisation of intersection control can be achieved to maximise throughput of users at the intersection. IoT and real-time data from individual intersections would also facilitate network level traffic management to prevent the onset of congestion by controlling upstream flows and spreading the traffic volumes over time and space.

- **A healthy intersection** where a proper right-of-way is allocated to active modes of transport, including pedestrians and cyclists. Minimising heavy vehicle emissions from stop-and-go at traffic lights should also be considered as an objective to minimise negative health impact on all users.
- **An accessible intersection** where sufficient right-of-way is allocated to individuals with mobility impairment. This could include prolonged green times for wheelchairs, individuals with walking assistance and elderly who walk slower.
- **A sustainable intersection** where active and low-footprint modes of transport are prioritised and promoted. Public transport should be prioritised by green light extensions and early greens, and similar right-of-way should be allocated to cumulating crowds of cyclists, pedestrians and batch arrival of passengers from public transport.

Every intersection, depending on geometric design, neighbourhood land use and position in the network, may display different pattern of usage and variability of demand within and across days. Some intersections are dominantly used by private vehicles and some accommodate multimodal travellers. Depending on time of day and location, some intersections may also bear a heavy weight from freight trucks and heavy vehicles. Depending on patterns of users and demand volumes, urban intersections may expose their users to different levels and types of safety risks and efficiency issues. Insights into traffic volumes, flow, potential conflicts, safety risks and near miss experiences carried out for individual intersections can shed light on what types of interventions are essential and what pieces of technology can serve those needs most effectively.

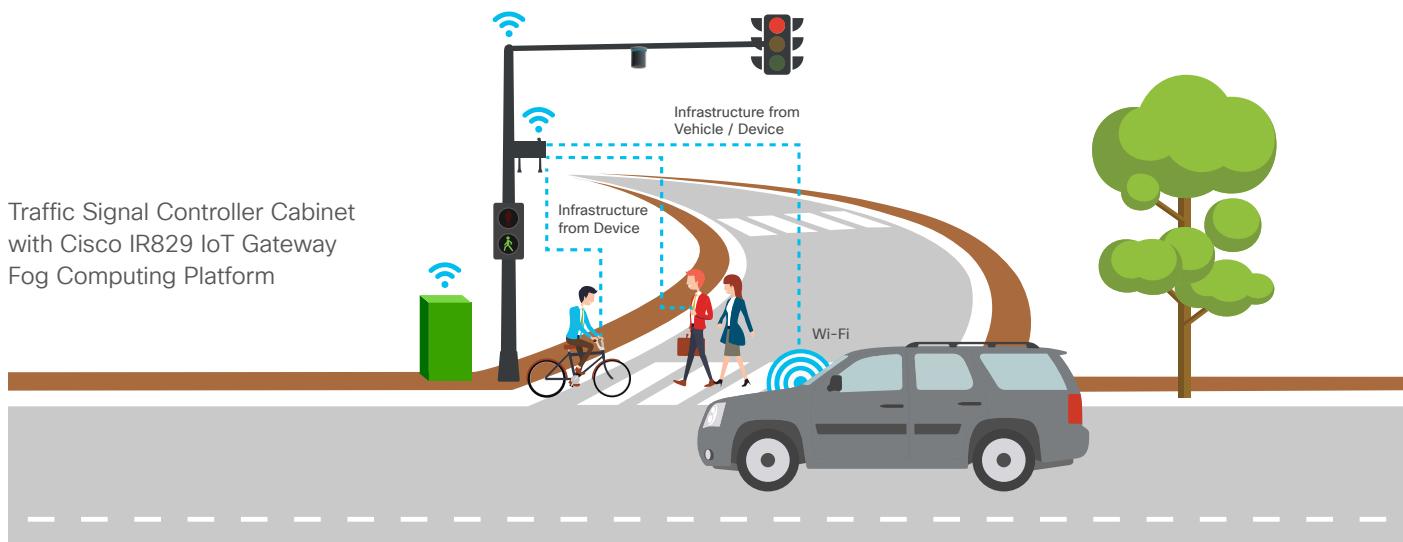
12. https://eng.unimelb.edu.au/__data/assets/pdf_file/0016/3008311/aimes-white-paper.pdf

Creating a safer and more efficient environment for all road users

This project belongs to a series of collaborative transport technology trials conducted within the Australian Integrated Multimodal Ecosystem (AIMES) which is an academia-industry-government partnership program founded by The University of Melbourne in 2016. The AIMES testbed provides a large scale, complex and multimodal urban environment for live transport technology and operations experiments. The AIMES ecosystem includes a network of diverse intelligent and distributed sensors technologies, covering an area of over 6 km² at the east side of Melbourne University (City of Yarra and City of Melbourne). This area includes 100km of roadways bound by Alexandra Parade to the north, Victoria Street on the south, Hoddle Street on the east and Lygon Street on the west, plus the Eastern Freeway and Eastlink.

The Smart Intersection trial focussed on proving accuracy and effectiveness of traffic flow assessment using a Cohda Wireless Wi-Fi solution at two intersections within the AIMES testbed. These intersections (Nicholson St./Johnson and Princes St/Canning) were chosen based on their layout and the mix of pedestrian, bicycle and vehicles at a high enough traffic density.

Figure 2: Typical Intersection Equipped with Wi-Fi Solution



Cohda Wireless Road-Side Units (RSU) passively listened to the “pings” regularly sent by Wi-Fi enabled devices in the vicinity of an intersection and sends this information to a Cisco IoT Gateway that provides local Edge/Fog compute capability. This data is then processed at the Edge, to calculate position of road users. As road users traverse the intersection, an accurate picture of their movements with an accuracy down to a lane level is captured. Once analysed, data is also sent to the Cloud for further integration through Cisco’s Kinetic IoT Data Fabric. This Edge and Fog compute capability allows local data to be captured and processed at the edge of the network reducing time latency for sensitive and safety critical applications, while also reducing volume of data being sent to the Cloud.

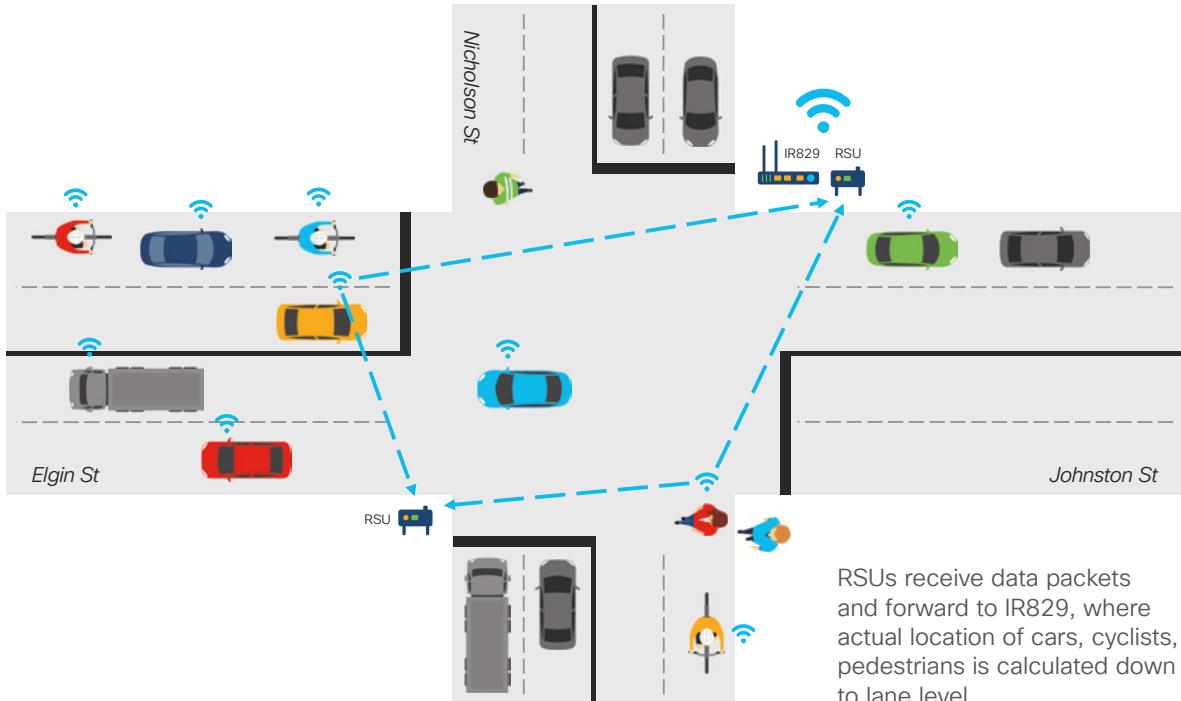
Figure 3: High level solution overview



An advantage of this solution is that it doesn't require any special equipment or an application for the road users. Furthermore, the solution provides two key technical differentiators, being: (i) more accurate positioning of road users, especially in dense ‘urban canyons’ where satellite positioning can be problematic, and (ii) the ability to monitor road user interactions and detect when one road user is under threat of collision from another (e.g. near misses). This and many other applications have a low latency tolerance. This is where Cisco Edge and Fog computing play a key role. Edge computing brings real-time processing, analyses and decisions closer to the data source to reduce time latency for sensitive and safety critical applications.



Figure 4: Intersection setup



A typical intersection deployment is shown in Figure 4. The Wi-Fi devices that are analysed may be:

- In-vehicle Wi-Fi Access points and Smart phones (potentially several depending on occupants)
- Pedestrians carrying smart phones
- Bicyclists carrying smart phones
- Motorcyclists carrying smart phones

Technical Note

As not every Wi-Fi device transmits while at the intersection, and transmission intervals can be aperiodic; the statistics obtained should be considered a sampling of the true population.

Privacy

Any infrastructure monitoring the wireless communication channel (over the air) needs to respect the privacy of owners of transmitting devices. To ensure this, only the meta-data associated with a packet is stored and packet contents are not logged or reported. Most transmitting devices (more than 80%) already use a randomised local MAC address for their probe packets (thus they are not identifiable). For the remaining devices with unique global MAC addresses, a hash of the MAC address based on a temporary key is stored, and this temporary key is only shared between RSUs but not stored or logged in the system. This ensures that the original unique MAC address is not logged or reported and cannot be traced back to the original MAC address.

Results

With the use of spatial data analytics this solution analyses the data for positional information, such as traffic flow statistics of vehicles passing through an intersection. In this case, spatial data analytics depends on the position of devices such as mobile phones, Wi-Fi access points and other Wi-Fi devices in and around the intersection. The accuracy of the positioning system drives the higher layer statistics such as lane level queue length and speed estimates.

The results for this solution involved validating the positioning accuracy of a Wi-Fi device at the intersection.

To represent a Wi-Fi equipped car a Wi-Fi device (TP-Link Wi-Fi travel router) was used.

Figure 5: Nicholson Street – Johnston/Elgin Street intersection in Melbourne



Map data ©2019 Google

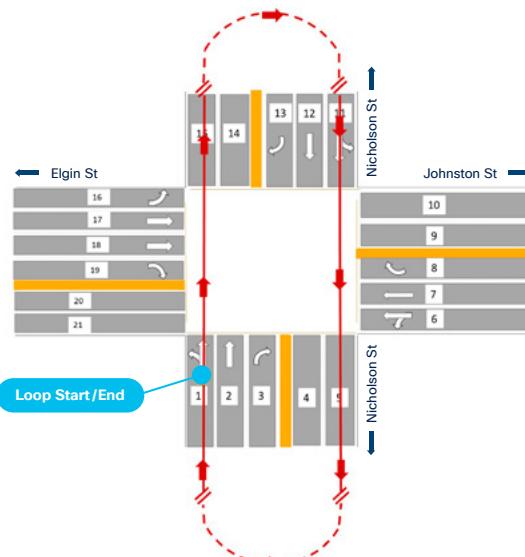
Many typical driving manoeuvres were performed around this intersection to validate the positioning system performance from all connected roads. Three different intersection manoeuvres were conducted through this intersection:

- **Case 1:** Straight
- **Case 2:** Left turn
- **Case 3:** Right turn

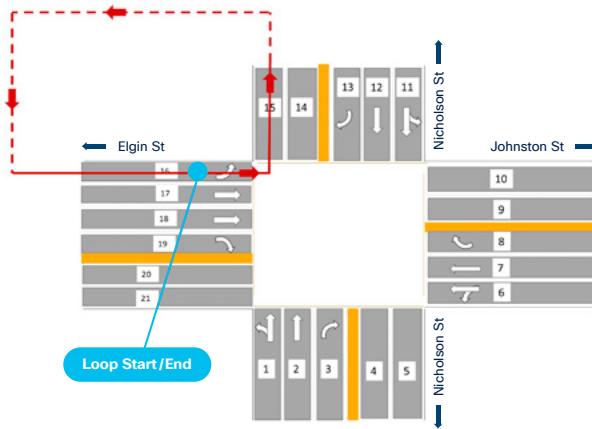
These manoeuvres are illustrated in Figure 5. Each manoeuvre was conducted several times. Most drives included occasions where the car stopped at various positions and these stopped positions are used to validate queue length analysis. Associated with each manoeuvre through the intersection is a pair of lanes, one used for entering the intersection and another used for exiting the intersection. Each such pair is referred to as the entry-exit lane transition or entry-exit lane pair. A total of 24 entry-exit lane transitions were completed during initial testing.

Figure 6: Validation drives through the intersection

Case 1



Case 2



Case 3



For each of the Use Cases the following validation was completed:

- **Position Performance:**
Use Case 1 & 4
- **Queue Depth Validation:**
Use Case 3
- **Speed Validation:**
Use Case 2

Position performance:

The positioning performance of Cohda's Wi-Fi Solution was validated against the reference GNSS for the three cases used as shown in Figure 7.

Case 1 the car drove straight through the intersection from (South to North and vice versa).

Case 2 the car is making left turns (coming from West and going to the North).

Case 3, the car is making right turns (coming from the West and going to the South).

As shown in Figure 7, the Cohda Wireless Wi-Fi Solution is able to infer the correct entry-exit lane transitions 23 out of 24 times, i.e. a true positive rate of 95.83% validating positioning accuracy for Use Case 1: Lane Level Traffic Flow and Use Case 4: Pedestrian Traffic flow and Queue length.

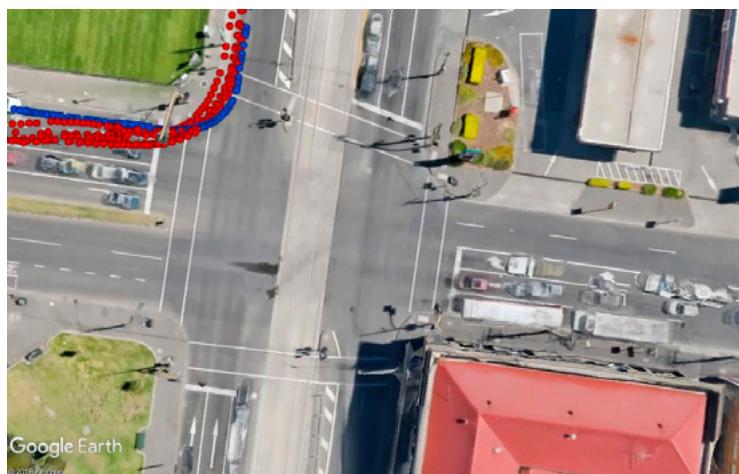
It is also important to note that the reference system (GNSS) has errors of up to 4 meters.

Figure 7: GNSS (red) and Wi-Fi positioning (blue) performance

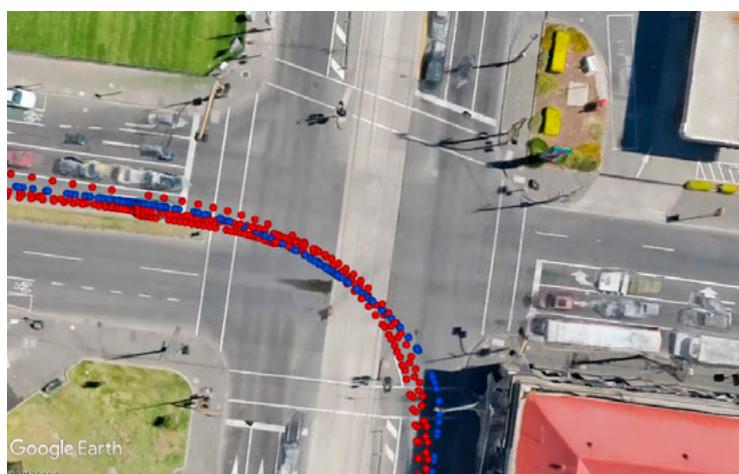
Case 1



Case 2



Case 3



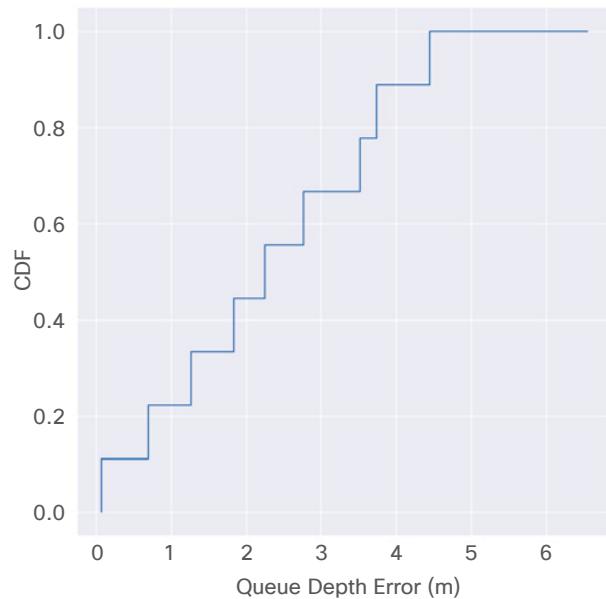
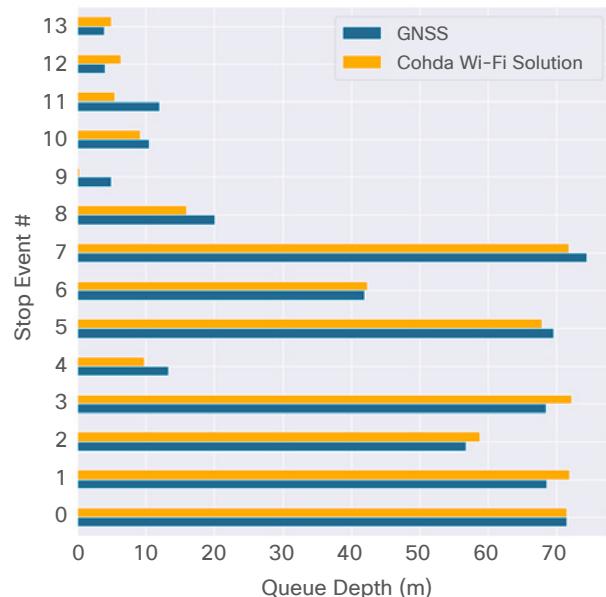
Queue depth validation:

Queue depth is defined as the length of queue in meters on a road lane at an intersection. If the position of all cars in the queue is known, then it can be derived by measuring the length from the stop bar to the last car in the queue. In order to validate this, points where the test vehicle was stationary were noted using GNSS and their distances from the stop bar were measured. These distances are taken to be references for validation. As part of this validation, the queue length for a lane is estimated as the distance from the intersection stop bar containing 95% of the vehicles stopped in that lane.

The same comparison of Wi-Fi against GNSS was performed on all stopping events across all cases where the test vehicle stopped during trials. The results as summarised in Figure 8 show the comparison for individual events and the corresponding cumulative distribution function (CDF) of the queue depth error between Wi-Fi and GNSS.

The CDF of the queue depth error suggests a 95th percentile error of about 4 metres. Extrapolating this to a Gaussian distribution of cars like our test vehicle gives a *mean queue depth error of 2.68 metres, with a 95% confidence interval of (1.65 metres, 3.71 metres)* as validation for Use Case 3: Lane Level Traffic Flow detecting and reporting on queue length.

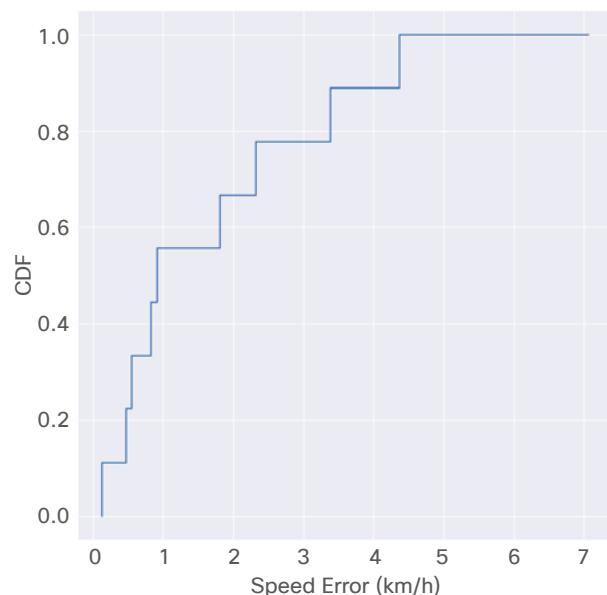
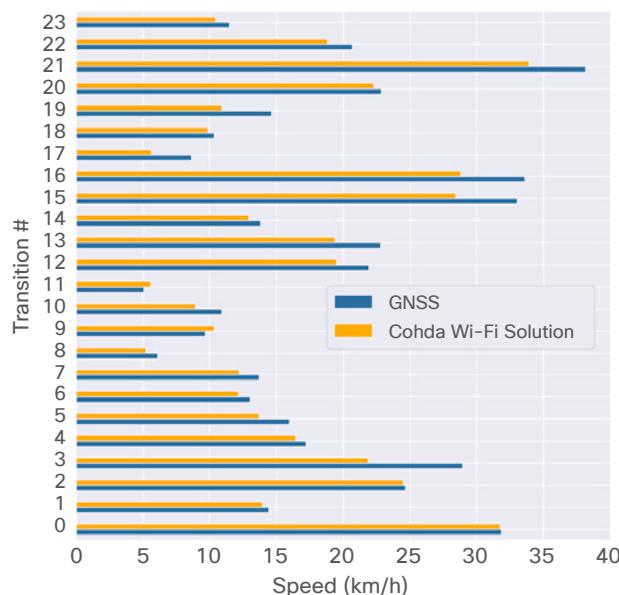
Figure 8: Wi-Fi positioning queue length performance against GNSS (reference)



Speed validation:

Validation of the average speed associated with a given transition through the intersection has also been performed for Use Case 2: Lane Level Traffic Flow detecting average vehicle speed. The results for the test vehicle across all 24 entry-exit lane transitions are shown in Figure 9. As can be seen, the *95% percentile error for these cases between Cohda's Wi-Fi Solution and GNSS is 4km/h. It also has a mean speed error 2.01km/h, with a 95% confidence interval of (1.67 km/h, 2.37 km/h).*

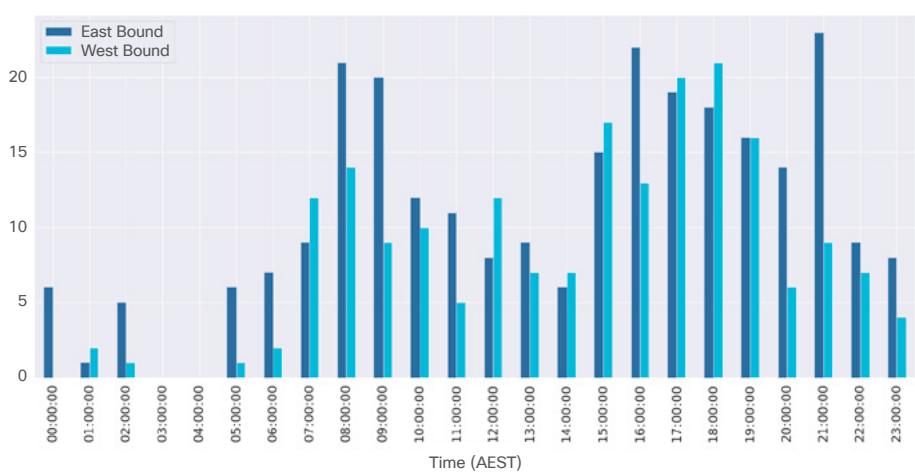
Figure 9: Speed performance of Wi-Fi positioning system vs GNSS (used as reference)



Additional Lane Level Insights: Intersection Data Flow Statistics

Other traffic flow statistics can also be inferred from the intersection using Wi-Fi data with lane level accuracy. For example, using the Cohda passive positioning algorithm, which allows the position of third party devices to be determined, statistics grouped by the direction of travel or lanes for a given leg of an intersection can be inferred. Figure 10 shows the traffic flow statistics along Johnston St (eastern leg of intersection) by the direction of travel, i.e. east bound or west bound.

Figure 10: Hourly Wi-Fi based traffic flow along the eastern leg of the intersection, grouped by direction of travel



The same statistics can be further decomposed into lane-level statistics for greater insights on lane utilisation. This is depicted in Figure 11, where the greyscale stacked bar is the decomposition of the east bound traffic shown in Figure 10, while the coloured stacked bar is that of the west bound traffic. The legend in the figure refers to the name of the lanes involved and their position is illustrated in Figure 12.

Figure 11: Hourly Wi-Fi based traffic flow along the eastern leg of the intersection, grouped by lane for each direction of travel

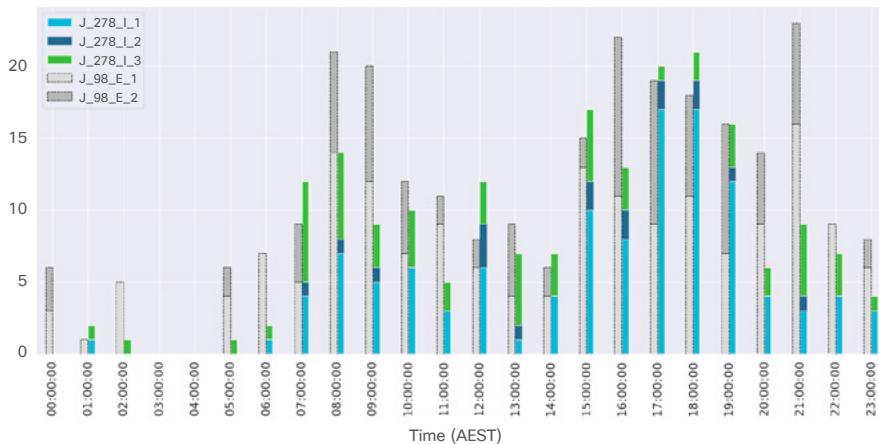
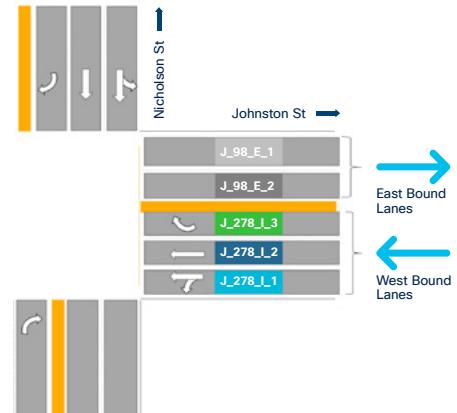


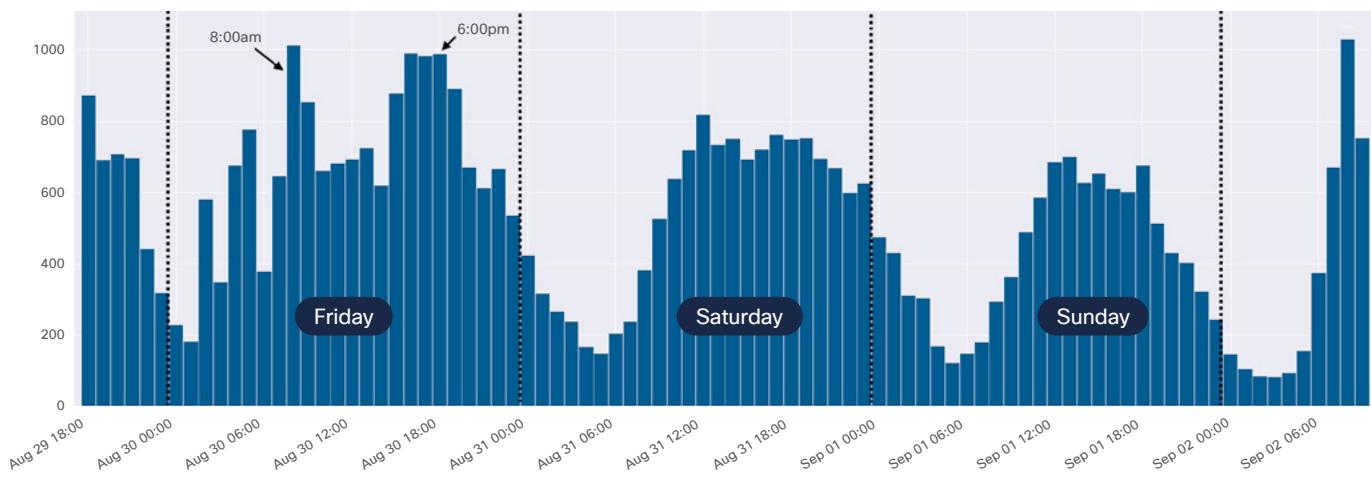
Figure 12: Lanes whose names are shown in Figure 11



An aggregate view of an hourly log of three days' worth of Wi-Fi traffic through the intersection is shown in Figure 13.

We can see that the data recorded from Wi-Fi devices is proven to be consistent with the expected traffic flow at this intersection with peaks and weekend traffic.

Figure 13: Hourly Wi-Fi based traffic flow through the intersection



Beyond IoT Insights

The technology verified as part of this trial lays a foundation for future solutions focusing on safety and efficiency of our roads. The current setup extended across a network of intersections and corridors can expand the depth and breadth of insights collected. For example, capturing trip origin/destination matrices, including mode of travel, purpose and time providing additional insights for strategic demand forecasting for road operators as well as enhancing user experience with reliability on their journey planning based on the analysis of this data over time. Monitoring road user (pedestrians, trams, vehicles etc) interactions can provide insights into near misses and overall risk profile of intersections. Advancement in data insights can also be extended to predictive analysis where this solution will look to predict such instances as travel delays.

Emergency Vehicles, Transit, and Freight Vehicles will also benefit as this solution can offer traffic light prioritisation resulting in more efficient travel times. This is critical for emergency vehicles as every second can save a life. Keeping large vehicles moving on the roads has a direct impact on traffic flow and the reduction of CO₂ emission into our environment.

These new insights can help unlock a wide range of applications targeting safety and efficiency.

For example:

- Emergency vehicle routing and prioritisation
- Driver alert when threat of collision is detected
- Input into traffic signal timing and distribution decisions
- Provide safety assessments at key intersections in areas of high traffic flow (e.g. identifying white spots and black spots)
- Anticipate and manage traffic impact at the end of large public events
- Input into prioritisation of network infrastructure investment
- Feed into AI to help direct traffic more effectively based on actual traffic conditions
- Support for autonomous vehicles

This solution also provides an infrastructure that is future proofed for the roll-out of V2X in Connected Vehicles and Connected Autonomous Vehicles as this system is upgradeable to DSRC or C-V2X.



Conclusion

Tighter integration between cars, infrastructure, pedestrians formally known as Vehicle-to-Vehicle (V2V), Vehicle-to-Infrastructure (V2I), and Vehicle-to-Pedestrian (V2P) communication – collectively called Vehicle-to-Everything (V2X) – offer great potential to improve road safety, reduce traffic congestion, and lower the environmental impact of transportation. However, these solutions have a dependency on mass adoption and specialised equipment thus creating a major barrier and a delay in deployment.

Through this trial it has been proven that IoT insights based on WiFi and Edge/Fog computing can provide a near real-time view at a lane level of road user performance. It can be applied across intersection and corridors with minimal infrastructure, setup and training.

The deployment of this solution is also fast and efficient, leveraging existing roadside infrastructure and causing minimal disruption to road users. The immediate benefits are varied and rich while also providing a path to V2X for when vehicles are so equipped.

By leveraging this technology to connect vehicles, pedestrians and roadside infrastructure, customers can begin to address the challenges of roadway management, accidents, and congestion. Cities can improve safety by identifying poor performing roadways and intersections and respond accordingly to improve traffic flow and intersection traffic planning, improve congestion with freight and traffic prioritisation software, and reduce CO₂ emissions by optimising the routes of heavy freight and public transport vehicles.

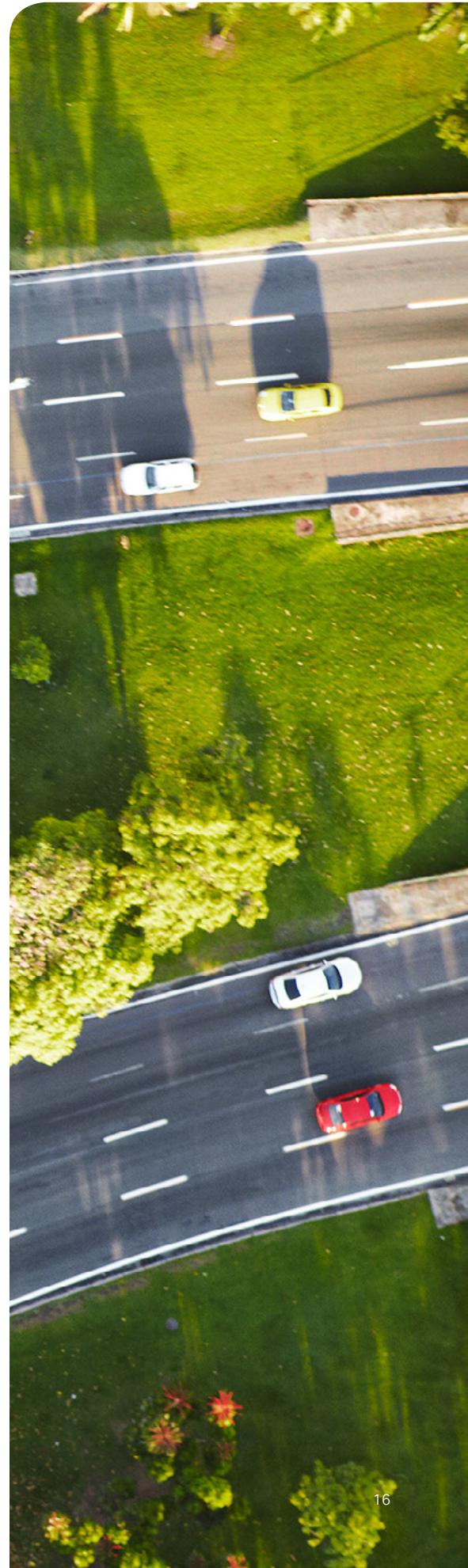
In collaboration with



Department of Transport



A collaboration led by CISCO



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