Sensor Aided Beamforming in Vehicular Environment

Moh Chuan Tan[1, 2, a)], Minghui Li[1], Qammer H. Abbasi[1], Muhammad Imran[1]

[1] James Watt School of Engineering, University of Glasgow, Glasgow G12 8QQ, United Kingdom
[2] Research and Development Department, RFNet Technologies Pte Ltd, Singapore 319319
[a)] Corresponding author: tmohchuan@rfnetech.com

Abstract — **Sensor fusion is a well-known technique to harvest the raw data from various type of sensors and generate a more accurate prediction on certain operation parameters that helps to improve the accuracy and efficiency of a big system. Many industries have been benefited from the sensor fusion such as robotic, agriculture, healthcare, autonomous vehicle, navigation and so on. In the smart antenna industry, the conventional beamforming is implemented in the costly field programmable grid array (FPGA) platform with the complex direction of arrival (DOA) algorithm. In this work, we are presenting a feasibility study on a lower cost alternative called sensor aided beamforming that make use of the raw data from the existing sensors in the vehicle, combined with some simple mathematically calculation to determine the beam angle of the mobile client and roadside infrastructure. We have presented a practical approach to study the sensor aided beamforming system in the real environment by simulating the beamforming parameters for a moving vehicle moves along the road that was pre-installed with roadside access points (AP). The result has proofed that the sensor aided method can be used to realize the beamforming in the smart antenna system, with the IoT sensors cost approximately less than U$20 compared with the FPGA price range of around U$200, the sensor aided beamforming will be a cheaper and affordable alternative to the conventional beamforming system that usually realized with the complex direction of arrival algorithm and higher cost.**

Index Terms—Sensor aided, beamforming, sensor fusion.

I. INTRODUCTION

The advancement of internet of things (IoT) has enabled the various type of sensors onboard the vehicles, the most relevant automotive sensors are GPS, accelerometer, gyroscope, magnetometer etc., which can be easily integrated into communication gateway or commercially available as off the shelf standalone module. Such sensors may already available in many of the vehicles in the public transportation sector. The application of the sensors is not simply providing the raw data, it will be combined through sensor fusion to produce the data in other forms that are more accurate and targeted to perform more tasks.

Over the years, many applications have been benefited from sensor fusion technology. A study report on sensor fusion utilizations in healthcare was presented in [1], the paper provides a survey on different multi-sensor fusion techniques in IoT for healthcare, including their requirement and applications, fusion techniques were discussed such as fuzzy logic-based, Baysian-based, Markov process-based, and Dempster-Shafer theory-based. The IoT sensor fusion in intelligent agriculture system [2] has been reported, regression trees method was used on the 8 different data related to light, temperature, humidity, rain, soil moisture, atmospheric pressure, air quality, and dew point were collected and the study was done to reduce the number of sensors by sensor fusion. For driving assistance or autonomous vehicle [3], the safety of future autonomous vehicles was discussed that includes the problem when the sensors data was shared between the vehicles and [4], the adaptive cruise control (ACC) system by utilizing cloud and sensor fusion by adaptive Kalman filter. Another application, the sensor fusion for indoor air quality monitoring [5] was implemented by using the fractional-order modelling and control (FOMCON) toolbox providing overall air quality alerts in a timely manner for accurate prediction with enhanced performance against measurement noise and non-linearity. Sensor fusion also utilized in the smart city for public space monitoring with IoT sensors [6], a data processing module was developed to capture public space utilization with renewable wireless sensor network (RWSN) platform using pyroelectric infrared (PIR) and analog sound sensor to monitor the public space utilization. In the mobile robot localization [7], data from various sensors such as accelerometers, gyroscopes and low-cost encoders were combined to determine the continuous and accurate location of the mobile robots. To the best of our knowledge, there has been no research report so far concerning the usage of IoT sensors in the beamforming system.

In this work, we are conducting a sensor aided beamforming antenna system study in the practical vehicular environment aimed to validate the alternative method to realize the beamforming antenna feature. Beamforming antenna is an electrically steerable antenna that concentrates its beam towards the interest direction and nulls off other direction, beamforming is a well-known technique to overcome the air space congestion and wireless interference in the wireless system. Combining the raw data from the onboard sensors such as GPS, accelerometer, gyroscope, odometer, Bluetooth low energy (BLE) with sensor fusion to provide the accurate location, speed and heading of the mobile client that can be used to perform the beam angle calculation.

The rest of the paper is organized as follows, in section II we elaborated the concept of the sensor aided beamforming antenna, follow by section III, the sensor aided beamforming in transportation environment is explained in details, including the type of sensors and method to calculate the necessary parameters that are required for beamforming functions. The practical simulation results of the sensor aided beamforming are presented in Section IV, and finally, section V concludes the paper.

II. THE CONCEPT OF SENSOR AIDED BEAMFORMING

Considering the operation of the public buses and train, the servicing routes for the buses are fixed according to their service map, similarly to train, where the rail tracks are fixed and the trains always follow the dedicated route when in operation. This is one of the advantages that the smart beamforming antenna designers can leverage on. With the fix geographical location of the wireless infrastructure, and the fix location of the equipment being mounted in the vehicles, as well as the predetermined direction and route of the vehicle on the move, we can combine the information gathered from the onboard sensors such as GPS, accelerometer, gyroscope, odometer, BLE etc., utilizing the sensors fusion method by combining the sensory data with the native beamforming algorithm to produce the beamforming direction between the base stations and the mobile clients. This method is also set to reduce the complexity and processing effort of the native beamforming algorithm when combined with the sensor fusion.

GPS is the most common sensor in the vehicular industry, it received signal from multiple satellites and provide the useful positioning data, utilizing the simple and matured specification called National Marine Electronics Association, NMEA-0183 to communicate with the host processor. The protocol provides the geographical position of the receiver such as longitude, latitude, and altitude, as well as time, speed and heading information. It is widely used in vehicle positioning and navigation-related applications.

When the vehicle is moving into the underground tunnel for a short instance of time where it lost the GPS signal, the Dead Reckoning (DR) feature [8] can recover the navigation data with the aid of other sensors such as accelerometer, gyro meter and odometer. The accelerometer detects the acceleration of the vehicle, the acceleration can be converted to velocity, micro-electro-mechanical systems (MEMS) accelerometer is the most used accelerometer in electronic devices. Gyroscope sensor is to measure the rotational angle of the moving vehicle, the deviation of the vehicle from its original orientation can be calculated. The odometer is used to measure the distance travelled by the vehicle. Most of the vehicles already have some of the sensors integrated into the vehicles control system, the sensors information can be retrieved via the Controller Area Network (CAN bus) interface.

III. SENSOR AIDED BEAMFORMING SYSTEM

The vehicle is pre-loaded with map includes the geographical location of all the access points (AP) installed as the roadside infrastructure. When the vehicle is on the move, the sensors data will be collected and through the aids of sensor fusion to produce the vehicle information such as location, speed, time and heading information, with the known location of the AP, the system will be able to determine which AP the vehicle should connect to and at what angle the beamforming antenna should concentrate its beam to have the optimum point to point connections. When the vehicle is passed the AP, the system can predict which is the next AP and its location for the moving vehicle to roam to, while the mobile client prepared to roam over, the beamforming engine will dynamically steer its beam towards the targeted AP. The location and heading information of the moving vehicle will be transmitted to the backend, the back end will use this information to determine the location and direction of the mobile vehicle with respect to the AP that is serving the connection and steers its beam toward to vehicle.

The sensors aided beamforming diagram that combined with the light direction of arrival (DOA) engine of the next generation beamforming system is presented in Fig. 1. With this hybrid approach by combining the sensor fusion output with the light computation output from the DOA engine, it can further improve the accuracy of the beam steering compare to the method with DOA itself. Furthermore, the existence of sensor data will reduce the processing complexity of the DOA engine, hence reducing the processing power of the DOA module.

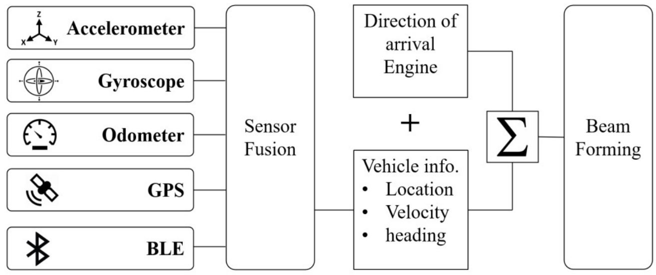

Fig. 1. Combination of sensor fusion and light direction of arrival for the future beamforming antenna system.

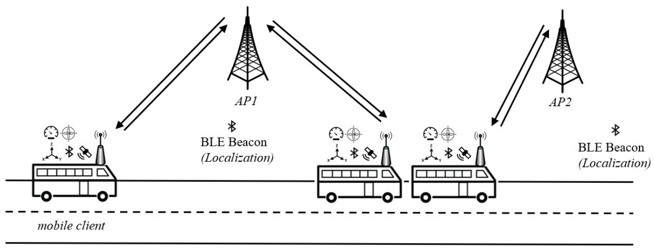

Fig. 2. Operation scenario of the IoT sensors aided beamforming system.

The illustrations of the IoT sensors aided beamforming system is presented in Fig. 2. The mobile client is installed with IoT sensors and wirelessly connected to the roadside infrastructure via the smart antenna system. The localizations BLE beacon is installed along the roadside to provide additional location information to improve the location accuracy of the mobile client. We would like to discuss 2 operation scenarios in this setup, i) with reliable GPS data, for example, clear sky and ii) when GPS signal is not available such as the vehicle is inside the tunnels or its moving in the urban area with high rise building where reliable GPS signal is limited.

For scenario i) operation with reliable GPS data, the APs that are permanently mounted at the roadside are with known geographical coordinate and the mobile clients can obtain their location information from the on-board GPS receiver. The 2 APs are located at the location *AP1* and *AP2* to provide communication for the passing by vehicles, the vehicle with wireless mobile clients and GPS receiver installed is moving along the road heading to the right, the mobile client will roam from *AP1* and *AP2*, and *m1*, *m2* and *m3* are the locations of the mobile client along the road. The top view of this operation scenario can be represented as a diagram in Fig. 3. Φ_m and Φ_{AP} are the bearings between the mobile client and the AP reference to the north, d is the actual distance between the mobile client and the AP while the mobile client is on the move.

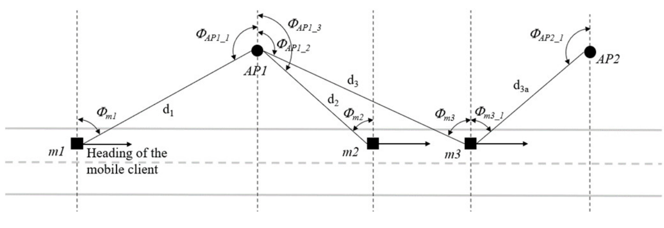

Fig. 3. Top view of the sensors aided beamforming system.

With the longitude and latitude of both AP and mobile client are known, the distance and bearing between the 2 points can be calculated [9]. The distance, *d* between point 1 and point 2 can be calculated using formula (1),

$$d = \operatorname{acos}(\sin Lat1 \times \sin Lat2 + \cos Lat1 \times \cos Lat2 \times \cos(Lon2 - Lon1)) \times R \tag{1}$$

The bearing, *be* from point 1 to point 2 can be calculated using formula (2) to (4),

$$x = \cos Lat1 \times \sin Lat2 - \sin Lat1 \times \cos Lat2 \times \cos(Lon2 - Lon1) \tag{2}$$

$$y = \sin(Lon2 - Lon1) \times \cos Lat2 \tag{3}$$

$$be = \operatorname{atan2}(x, y) \tag{4}$$

Where R is the radius of the earth (6,371 kilometers), d is the distance between 2 points in kilometers and *be* is the bearing from point 1 to point 2 in degree (0° means heading north, the positive value represents clockwise from the north and the negative value means counterclockwise from the north), *Latn* and *Lonn* are the latitude and longitude of point *n* in radians.

The antenna beam direction of the mobile client, Φ_m (0° denotes pointing towards the front of the mobile client) and AP, Φ_{AP} (0° denote pointing to the north) can be calculated as,

$$\Phi_m = be - mobile\ heading \tag{5}$$

$$\Phi_{AP} = 180° - be \tag{6}$$

Knowing the heading of the mobile client and the bearing between the mobile client and the AP, we can determine the direction of the antenna beam, hence the antenna beam for the mobile client and the AP can be steered towards each other. The distance between the mobile client and APs are constantly monitored, to ensure it is always connected to the nearest AP, when the next AP is nearer than the current AP, the mobile client will prepare to roam over and hand over the beamforming coordination to the next nearest AP.

For scenario ii) where there is limited or no GPS signal coverage, the onboard IoT sensors will come to play. When the mobile terminal is moved away from the GPS coverage zone, it will make use of the last GPS fixed location with the help of DR via sensors fusion to perform the data interpolation and progressively determine the current location, speed and heading of the mobile client, following the same approach as described earlier, the beam steering direction can be calculated. Due to the location and heading information were obtained via interpolation from the last GPS fix and sensors fusion, the accuracy of the location and heading will be deteriorated over time, to overcome this, the BLE beacons can be installed at the fixed locations such and lamp poles and bus stops along the stretch of road where the GPS reception is poor. Each beacon will have known coordinates, when the mobile client associate with the roadside beacon, it will be able to reposition itself and offset the accumulated location error.

IV. Simulation Result and Discussion

To simulate the beamforming angle and roaming between the APs and the mobile client, we are making use of the sample route in Singapore around the Pan Island Expressway and Pioneer Road, we have plotted 10 numbers of APs in blue waypoints and the mobile client is moving through the 16 numbers of green waypoints starting from point A and end at point B, the heading direction of the mobile client is indicated by the dotted green arrows as illustrated in Fig. 4.

When the mobile client travels from point A to point B, it will track and roam to the nearest AP. The distances between the APs and the mobile client at different waypoints are calculated using formula (1) and the results are shown in Fig. 5, the mobile client always connected to the nearest AP, in this case, the mobile client at location *m1*, *m2* and *m3* will be connected to *AP1*, and it will roam to *AP2* when it moves to locations *m4* and *m5* and so on.

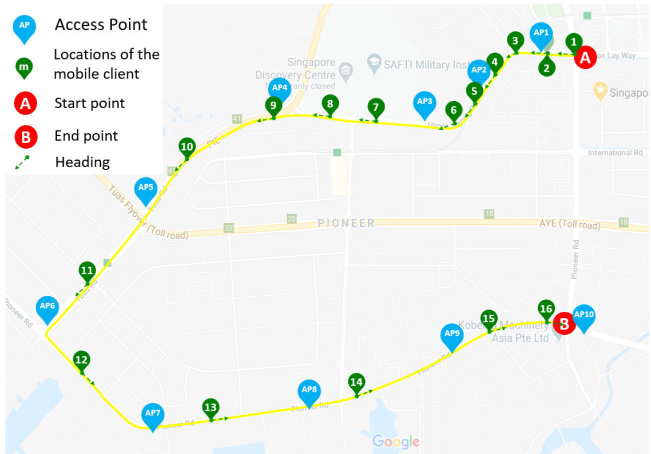

Fig. 4. Access Points (blue) and mobile waypoints (green) for beamforming simulation.

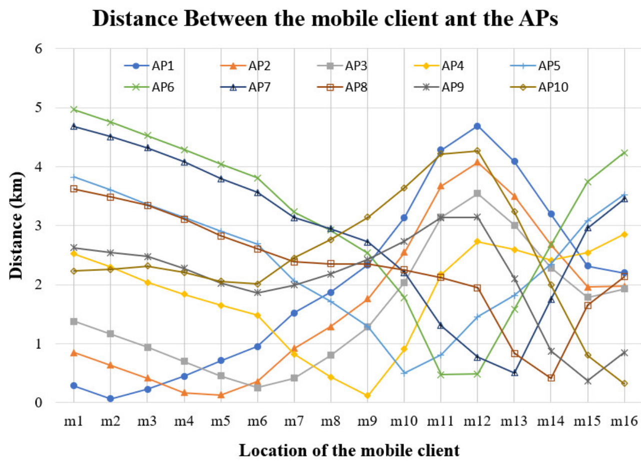

Fig. 5. Distance between the mobile client and the Access points.

The next chart indicates the calculated beamforming angle for the APs and mobile client. When the mobile client travels from point A to point B, the antenna radiating beam of the mobile client and the APs will steer dynamically to each other and the beam angle is calculated using formula (5) and (6), the calculated Φ_m and Φ_{AP} when the mobile client is moving from point A to point B and roamed through the APs are plotted in Fig. 6.

Details of the beamforming direction can be explained using Fig. 7, take an example, the mobile client is at location *m2* is moving at -88° heading and connected to *AP1*, the beam steering angle for the mobile client is 42.4° and 134.2° for the AP. When the client continues to move, the new beam angle for mobile client and AP will be calculated on the fly using the instant location of the mobile client.

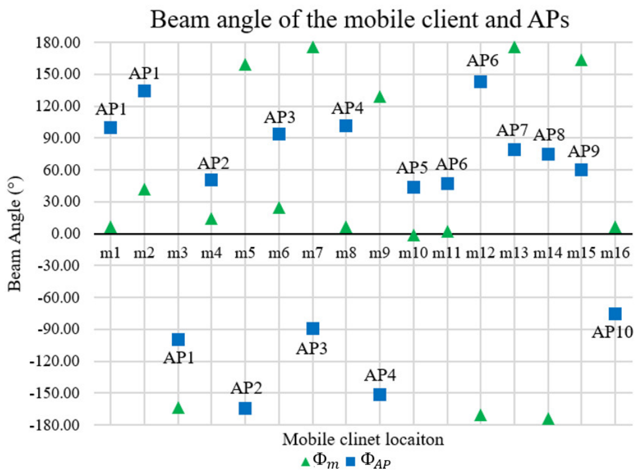

Fig. 6. Simulated beam angle for the mobile client and Access Points at location m1 to m16.

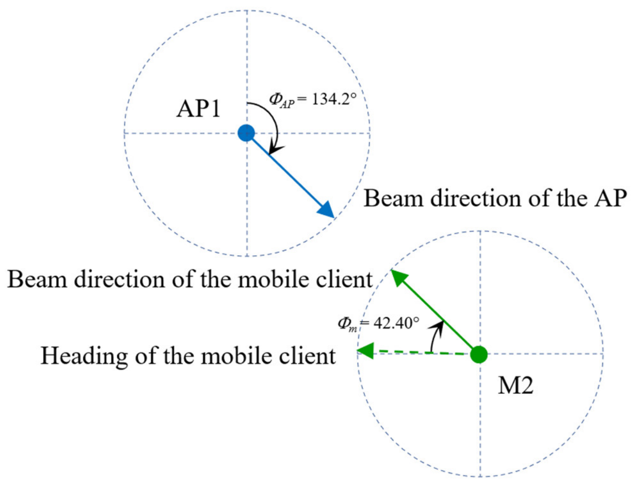

Fig. 7. Beamforming at location m2 where the mobile client is connected to AP1.

The study results have proofed that the sensors aided with GPS positioning data is able to determine the correct angle for the antenna beam in the smart antenna system. The estimated cost for a GPS module from Quectel [10], P/N: L26-DR with built-in accelerometer, gyroscope and wheel tick input is around U$10, and the commercial BLE module is cost around U$8 to U$10 compared to the FPGA with a price tag around U$200 and above. This technique can be deployed in the mobile terminal with lower processing power due to limited power source such as in the vehicular environment, the proposed method include lower-cost and faster estimation of the angle for the main beam between the mobile client and AP, the angle can be used alone or as an initial estimate to guide the DOA estimation and interference nulling.

V. Conclusion and Future Works

The fixed roadside infrastructures and fix operation route of the public transportation system, combining with the sensor fusion from existing IoT sensors such as GPS, accelerometer, gyroscope, odometer, BLE etc., and leveraging on the operation behavior and IoT infrastructure, the geographical locations of the mobile client can be determined and further computed into useful location-based information that helps the roadside APs and mobile terminal to coordinate and determine the accurate beamforming angle within them. The method was validated with the simulation result in the practical road in Singapore, the results revealed that the sensor aided beamforming method is able to provide the accurate beamforming angle in the smart antenna system. This is expected to reduce the highly complex field-programmable grid array (FPGA) cost that is usually used in the conventional beamforming smart antenna system. The proposed modern smart antenna system is expected to set an important milestone in the smart antenna industry. The future work involves field trial, characterizations and assesses the accuracy of the sensor aided beamforming antenna.

Acknowledgement

The authors would like to acknowledge and express sincere appreciation to the Singapore Economic Development Board (EDB) and RFNet Technologies Pte Ltd for financing and providing a good environment and facilities to support the project.

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