AN ADAPTIVE SYSTEM FOR ANTENNA ALIGNMENT TO ACCESS SATELLITE TELEVISION FROM THE VEHICLE IN MOTION

Sourav DHAR, Rabindra Nath BERA, Debjyoti GHOSH
Department of Electronics and Communication Engineering
Sikkim Manipal Institute of Technology, Majitar, Rangpo, East Sikkim, India-737136
Email: sourav.dhar80@gmail.com

Mithun CHAKRABORTY
Department of Electronics and Communication Engineering
Surendra Institute of Engineering and Management, Siliguri, West Bengal, India-734009

Abstract: A software controlled adaptive system for antenna alignment is proposed here for DVB access from vehicle as a part of intelligent transportation system (ITS). This is achieved by measuring the SNR and then using motors to 3-Dimensionally move the receiver parabolic dish to align with satellite. Experiment is performed in two parts. In first experiment, a single motor is used to align a prototype Yagi-Uda antenna. And in second experiment, a prototype dish antenna is aligned using two motors which are controlled through software. An accelerometer is simulated to determine the direction of motion of the vehicle on which the receiver antenna is mounted. The initial alignment of the antenna by SNR measurement provides the data for alignment retention in transportation environment. MATLAB/SIMULINK platform is used to develop the master control software. Virtual reality is used to simulate the nonlinear motion of the car. Comparative results, with and without corrective algorithm, and the peak-to-peak SNR variation against antenna beam width is shown.

Key Words: Digital video broadcasting (DVB), Intelligent transportation system (ITS), Virtual reality, Antenna alignment system, Software defined radio (SDR), Fourth generation mobile communication (4G).

1. Introduction

Intelligent Transportation System (ITS) is a method of converging remote sensing, communication and information technologies and other advanced methods with transportation engineering to address transportation problems involving a complex interplay between technology; human perception; cognition and behavior; and social, economic, and political systems [1]. ITS utilize different types of sensors to convert physical world quantities outside the vehicle (such as other vehicles, road conditions, etc.) and inside the vehicle (such as tire pressure, break, other mechanical failures, etc.) to electronic signals which are then used for decision making. "Smart cars", to be used in ITS, must provide antennas for many different purposes, including safety, entrainment, voice communications, data communications, guidance, emergency, navigation, and locating functions [2]. Safety applications and non safety application are the two major categories of ITS applications. Automatic cruise control (ACC), Driver assistance systems (DAS) and Collision avoidance and warning systems (CAWAS) are some examples of safety application. On the other hand, internet access from car, vehicle to vehicle (V2V) and vehicle to infrastructure (V2I) communication, satellite television from car, radio taxi, and automatic toll collection are categorized as non-safety applications.

Different countries are using different standards for ITS. Thus, International Telecom Union (ITU) and International Organization for Standardization (ISO) in 2003, and promoted by the more recently created industry association – The CALM Forum – to develop a new family of ITS standards with the overall branding of "Continuous Air-interface for Long and Medium range(CALM)"[6]- [8]. The aim of CALM is to provide wide area communications to support ITS applications that work equally well on a variety of different network platforms. The decision on which platform to use in a particular country or for a given application would then be based on logical selection of pre-set criteria to make the best use of resources. Thus, CALM is intended to be platform independent, and therefore to avoid the battles over regional standards that have dogged existing ITS standards like DSRC. For instance, the basic CALM system architecture (ISO 21217) foresees

support for 10 main categories of network [8], and 22 different sub-categories each of which would need a different Service Access Protocol (SAP). Digital video and audio broadcasting (DVB and DAB) are included in CALM. Thus CALM supports the 4G vision [3,4,5] as shown in fig.1.

Interactive satellite services provision via a broadcast system is now well known for interaction in digital video broadcasting-satellite (DVB-S) networks, thus enabling for broadband satellite Internet access [9]. The standardization of DVB-return channel via satellite (DVB-RCS) [10] in 2000 introduced a pure satellite-based solution for interactive broadcasting. At the same time, in the terrestrial sector, the multiplexing of heterogeneous services — digital television, telephony, and Internet access, the so-called triple play — over the same channel opened new perspectives for the provision of integrated services via terrestrial networks like digital subscriber line (xDSL). The end users are able to enjoy broadband digital television (DTV) content, telephony connectivity, and fast access to the Internet while being totally independent of terrestrial access networks. In this sense, such a satellite platform could contribute toward the fading of the so-called digital divide [11]. The introduction of DVB-S2 [12] constitutes a great step toward the optimum spectrum usage by achieving a less than 1 dB approach to the Shannon limit and providing per-service real-time adjustment of transmission parameters, a feature called adaptive coding and modulation (ACM). By exploiting ACM, the satellite provider can adjust in real time the transmission parameters for each service, in relation to the propagation conditions of the corresponding site. In this sense the satellite capacity can be optimally exploited, and subsequently the cost of services can be drastically reduced. The application of DVBS2 ACM in satellite triple play, including technical issues involved in resource allocation, network design and deployment, and simulated system evaluation is presented in [13].

DVB requires a high gain directive antenna. This high directivity also requires a precise alignment with the satellite downlink beam. In commercial applications, the DVB receiver is static in their positions hence antenna is kept fixed once the antenna is aligned with satellite downlink. Providing DVB service in vehicle is a very challenging task. Changes in the direction of motion and the speed of the vehicle disorient the antenna. Also the signal may be completely lost when the vehicle enters a terrain where the line of sight is blocked by tall buildings. Thus automatic antenna alignment is the major requirement for accessing DVB from vehicle on the move.

A satellite reception system, with a movable automatic antenna, of television and radio signals is presented in [14]. Sherwood [15] has presented a deployable satellite antenna system with azimuth and elevation control. A self-aligning GPS antenna system is presented in [16] and a satellite receiver system, with alignment facility for multi-band consumer receiver antennas, is presented in [17].

In the present work we attempt to implement an antenna alignment system that can align itself to the direction of optimum SNR value of the received signal even when the vehicle is in the motion. The movement of the antenna is controlled by PC. The software for antenna alignment is developed in MATLAB/SIMULINK. The motion of the vehicle is simulated using virtual reality of MATLAB. The angular and radial motors are controlled for proper alignment of antenna especially when the vehicle changes its direction of movement.

2. Background of the work

Authors are involved for a multi-channel solution of ITS challenges. Remote sensing is used in ITS for safety applications. Authors have shown in [18, 19], how digital radar is effective to avoid collision. Ubiquitous communication is another major requirement for both safety and non safety applications. Authors have taken an initiative to design a robust vertical handover algorithm to provide seamless connectivity in heterogeneous radio access network scenario [20-22]. Convergence of both remote sensing and communication is presented in [23].

This work is an extension to the work presented in [18-23]. Here, an effort is made to watch uninterrupted television on the move. The software will be ported to a software defined radio (SDR) and a complete embedded system which will converge remote sensing, communication and DVB system for ITS will be developed.

3. Problem Definition

Signal clarity or "signal-to-noise ratio" is a key factor in optimizing the performance of any wireless communications product. RF line of sight requires a wider band of free-space signal path than visual line of sight. Signal clarity is best when the line of sight between antennas is precisely focused and free of all obstructions. Obstructions within the RF line of sight can

absorb the signal and sap it of strength or deflect the signal and cause multiple copies of the same signal to arrive at the receiver out of phase. The way radio waves fan out from their source resembles the way waves of water fan out from a vibrating object in a pool. Signal strength decreases as the signal fans out further from the first wave. An antenna deflects the waves and channels them in one direction. They then form a more focused conical shape and have greater strength. The signal is not spread evenly throughout the cone. In the same way that light is focused by a magnifying glass, an RF signal shaped by an antenna is strongest within a narrow area at the center of the cone. The area where signal strength is strongest is referred as the center lobe. RF signal clarity is one of the key factors in obtaining a high performance wireless communications link. While it is possible to transmit successfully over short distances with some obstructions in the line of sight, it becomes increasingly difficult to maintain a clear signal as the transmission distance increases. To achieve a clear signal between distant locations, we must maintain the clearest possible RF line of sight (LOS).

During motion it is very difficult to maintain an exact LOS. We've performed an experiment with terrestrial TV on motion. The result is shown in fig. 2. Initially antenna was properly aligned and picture quality was good. Then we started to move in straight line and there was good reception till we took a bend. As soon as there was a bend in the motion, we lost the signal. Again we aligned the antenna manually and the receiver started to receive the signal and the picture quality was as before. This experiment proves the necessity of LOS alignment of TV antenna.

4. Proposed Solution

Our objective is to make the antenna assembly system adaptive so that it points to the direction of optimum SNR (signal to noise ratio) value of the received signal even during the motion of the vehicle.

It is assumed that the antenna originally points in the direction of the satellite. During the motion of the vehicle, the accelerometers continuously measure the change in direction in all the three planes, i.e., increase in height of the vehicle and change in direction of the vehicle in horizontal plane. If the SNR drops below the threshold value, the antenna starts searching for signal in the last direction change until the SNR of the signal increases above threshold value. The antenna

assembly front end is shown in fig.3a. The radial motor moves the antenna in the X-Y plane while the angular motor moves it in the Z plane as shown in fig.3b.

We've performed two experiments to achieve this solution. Experiment 1 was performed to align the terrestrial TV antenna and experiment 2 was performed to align the dish antenna of satellite TV.

The objectives of self adjusting antenna are:

(1) Changing the orientation of the directional antenna with respect to changes in direction of motion of the vehicle in all the three planes (X, Y and Z).

(2) Automatic scanning and tracking of the signal in case of complete loss of direction.

5. Experiment -1

This experiment is performed as a stepping stone to align antenna in motion. Here a terrestrial TV antenna (Yagi-Uda) is aligned with help of a stepper motor (fig. 4a).The connection block diagram for the experiment is shown in fig. 4b. The stepper motor is controlled by a computer program. The program is written in MATLAB/SIMULINK platform. LN2003AN current amplifier is connected with parallel port of PC. The output of the current amplifier is driving the stepper motor. Thus a software controlled antenna alignment setup is established.

Fig. 5 is showing the SIMULINK model of the stepper motor control software. Here the terrestrial TV subsystem generates random SNR and the signal strength reference subsystem provides a reference SNR value. The motor controller compares the peak of current SNR value with the reference SNR. If the current SNR is less than the reference then the motor controller will issue a command to rotate the stepper motor till the received signal SNR is above the reference level. And hence the antenna alignment is achieved.

6. Experiment-2

Prototype Yagi-Uda antenna alignment problem was successfully solved through experiment-1. But this setup is unsuitable to align a dish antenna. For this we need two stepper motors as shown in fig. 3. A complex program is written to control two stepper motors.

Here SNR received at the receiver antenna is simulated by designing a SNR generator block. It is assumed that the SNR generation is free from

any momentary spikes or glitches. It is also assumed that the antenna is initially aligned to satellite beam. Due to the subsequent motion of the car, the SNR decreases. The self adjustment algorithm tries to overcome the effect by moving the radial and angular motors. The motion of these motors affects the SNR value received. Finally, the radial and angular motors are moved according to motion inputs generated by MATLAB program. Parallel port is utilized to convey these signals to the motor driver.

6.1 Simulink Model for SNR Generation

SNR is generated (fig. 6) by subtracting the corrective angular movements of the two motors from the actual angular movements of the car. Change in the radial angle (ΔØ) happens as the car changes its direction of motion (fig. 7a). Change in the azimuth angle (Δθ) occurs as the car moves certain distances in a particular direction (fig. 7b). The resultant position after movement is shown in fig. 7c.
Where,

Δθ → Distance traversed (including the vertical distance) / Reduction factor

ΔØ → (Horizontal distance traversed / Reduction factor) + Change in direction of motion of car

The motor movement signals are multiplied with the angular step size. The angular movements are integrated so as to maintain a memory of the total angular rotated antenna. Whenever the total angular motion exceeds 2π, the angular motion is reset to zero. Radial Motion of the car is calculated by subtracting the initial radial angle of the car from the rotation of the car and adding the result with distance ratio. Azimuthal Motion of the car is calculated by calculating the distance moved by the car and dividing that by an angular reduction factor.
Assumptions made while evaluating the radial and azimuthal motion of the car are:

(1) The distance of the car from the satellite is very large, and hence the azimuthal and radial angles vary very slowly with the motion of the car.

(2) The radial angular motion of the car depends upon the rotation of the car. If the car rotates by a certain angle θ, the radial angle also changes by the same angle, and the radial motor should move by the same angle.

The corrective angular motions of the motors evaluated are subtracted from the actual evaluated angular motions of the car. The maximum magnitude obtained is subtracted from 'beamwidth' and divided by the beamwidth. The resultant is multiplied with maximum SNR value. In case the resultant is less than zero, then the SNR value is set to zero. Beamwidth is a measure of the tolerance values of the deviation in corrected angular motion.

6.2 Simulink Model for Accelerometer

The static values of the accelerometer are found using the following equations:

$$A_x = g \times Sin(\psi_e) -----------(1)$$
$$A_y = g \times Sin(\psi_r) --------------(2)$$
$$A_z = g \times \{Cos(\psi_e).Cos(\psi_r)\} -----(3)$$

Where,
g → is the gravity.
A_x, A_y, A_z are the acceleration in X, Y and Z dimensions respectively.
Ψ_e → Elevation angle
Ψ_r → Roll angle
The dynamic values of acceleration due to change in velocities in three axes is evaluated by differentiating velocities with respect to time. These dynamic values are added with the static values to obtain the total acceleration. The integrated Simulink model for accelerometer is shown in fig. 8.

6.3 Simulink Model for Master Control Program

The master control program (fig. 9) is called by the "MATLAB Function" block. The inputs to the function are first vector concatenated. The outputs are retained so as to form a memory which serves as inputs to the function. The inputs which need to be retained are previous motor movement and previous SNR value. The switch is used to switch between the motor commands generated by the self adjusting algorithm and the signal searching algorithm.

6.4 The Virtual Reality

The need for a virtual reality world arises to simulate an environment with any parameters at no cost. To achieve our objective, we have designed a virtual world consisting of a car mounted with an antenna and an uneven terrain where the car traverses in a non-linear path. The position of the satellite is fixed and hence the

antenna-assembly has to constantly orient itself with the satellite by adjusting its azimuth and elevation. The virtual world is designed by using the V-Realm builder tool available with MATLAB [24].

As shown in Fig.10 the virtual world can be interfaced with a Simulink model using the VR sink block and the parameters of the virtual world are set from the model. The VR sink block acts as an interface between the virtual world and the Simulink workspace converting the port input values into corresponding axes values in the virtual world.

As we can see from the VR-viewer window in the top left of the figure, the footer shows the position of the view-point or the camera and the given case the camera is at the viewpoint of the observer.

The velocity of the car in X, Y and Z direction is generated and are passed through an integrator to produce the position of the car in X, Y and Z directions which are subsequently concatenated in vector form and sent to the VR Sink object. Also the horizontal rotation of the car is also calculated by the function 'atan(Vy/Vx)' and supplied to the VR Sink object. These parameters change the orientation of the car in the simulation.

6.5 Complete Simulation

The complete simulation is shown in fig. 11. The SNR generator block is basically simulating the received SNR depending on the vehicle motion. Variation in SNR can be observed in the scope. Motion of the car results in the variation in received SNR. The received SNR is consistently monitored and when SNR tends to fall bellow the threshold, the master control block takes the corrective measures by controlling the angular and radial motors. We have considered two bends in road, as shown in fig. 9, for simulation. The change in direction is sensed by accelerometer. We have assumed that there is no acceleration and car is moving with a constant velocity in straight road. Whenever there is a bend, the velocity changes which is detected by the accelerometer and hence corrective actions are taken. Thus by consistently monitoring SNR variation and acceleration the antenna alignment is achieved to ensure quality of service (QoS) for DVB access on the move.

6.6 Hardware Setup

Two motors are driven using the signals generated by MATLAB interface. The signals are sent via the parallel port to a L298 motor driver. L298 motor driver is a dual Full-Bridge Motor Driver capable of rotating two motors in both anticlockwise as well as clockwise direction.

Parallel port has 25 pins. Single strand wires are used to connect port pins with our circuit. Pins 2-9 are bi-directional data pins (pin 9 gives the most significant bit (MSB)), pins 10-13 and 15 are output pins (status pins), pins 1,14,16,17 are input pins (control pins), while pins 18-25 are Ground pins. Complete block diagram of the adaptive antenna assembly is shown in fig. 12 and the experimental setup is shown in fig. 13.

En_Rad & En_Ang are the enable inputs for the Radial and Angular Motors respectively. Inputs In1, In2, In3, In4 determine the direction of motion of the two motors according to the combinations given in Table I.

Table I: Operating combinations of DC Stepper Motor

In1/In3	In2/In4	Operation
0	0	No operation
0	1	Clockwise
1	0	Anticlockwise
1	1	No operation

6.7 Results

The SNR variation of the vehicle with respect to motion of the car is an important factor for deciding the efficiency of the algorithm. The graph shows the variation of SNR values as the car moves (fig. 14). Here, the automatic realigning algorithm is suppressed and the graph depicts the usual SNR behavior when no corrective measures are taken (fig. 14). Thus SNR drops down to zero. Fig. 15 shows the variation of SNR values, as the car moves, the automatic realigning algorithm takes care of the corrective antenna movements and is clearly visible how the SNR values are maintained above the threshold value. The graph is somewhat like a saw tooth wave. The reason is that the realigning algorithm comes into action only when the SNR value drops below the threshold value. Here, the threshold is set as 14 dB, so whenever it drops below 14, corrective movements are taken, and the SNR value rises. Again, it starts falling down and the same procedure is repeated.

If there is a rotation of the vehicle, i.e., change in the direction of motion, the SNR changes rapidly but still the realigning algorithm manages to keep it above threshold value (fig. 15).

The Sawtooth nature of the alignment can be smoothened by increasing the antenna beamwidth.

Table II lists the peak to peak variation in received SNR for different antenna beamwidth. The following graph (fig.16) is obtained by changing the beamwidth parameter of the SNR Generator. It is evident from fig. 16 that, if beamwidth is more then antenna alignment will be easier.

Table II: Variation in SNR (dB) with Beamwidth

Beamwidth (degree)	Peak-to peak SNR Variation (dB)
0.5	5
1	3.5
1.5	2.4
2	1.7
2.5	1.45
3	1.25
5	0.7
7	0.5
10	0.35
15	0.234

7. Discussion and Conclusions

The adaptive realigning algorithm works well for the car simulation in a virtual real world. The results reveal the necessity of the algorithm in maintaining faithful SNR values during motion of the car. Without the accelerometers the algorithm fails to track the signal when acceleration occurs or a change in direction occurs. The research works done in this field so far were mostly based on hardware control. This work has presented a software controlled antenna assembly which will be farther implemented through Software defined radio (SDR) and will be tested in a real world scenario for ITS applications. Thus this work is compatible to fulfill 4G vision of converging broadcasting, cellular and wireless local area networks.

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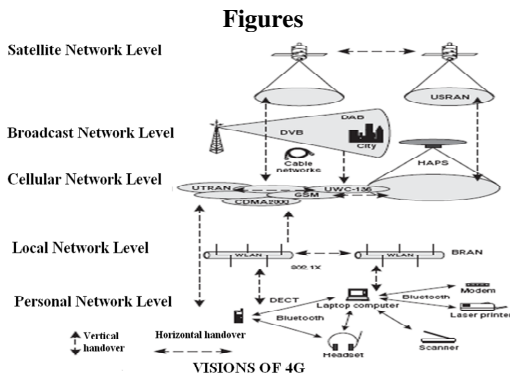
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Figures

Fig. 1: Convergence of networks in 4G [3]

Fig. 2: Picture distortion due to antenna rotation.

Fig. 3a: Antenna assembly front end.
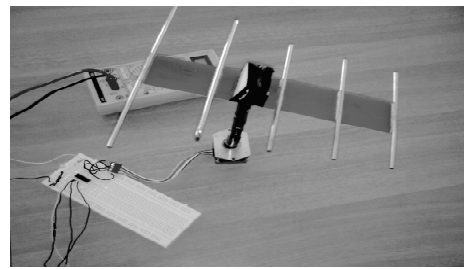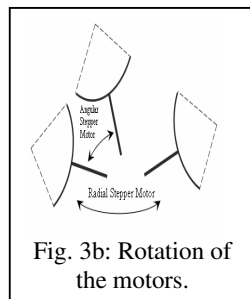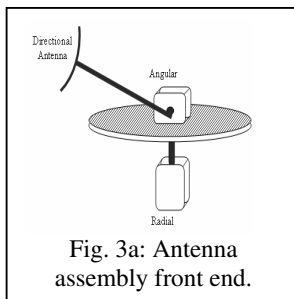

Fig. 3b: Rotation of the motors.

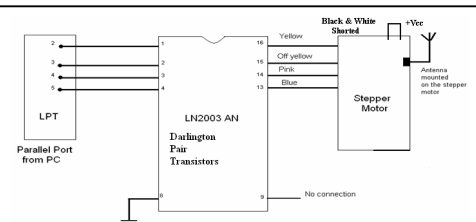Fig. 4a: Experimental setup for the alignment of prototype Yagi-Uda antenna.

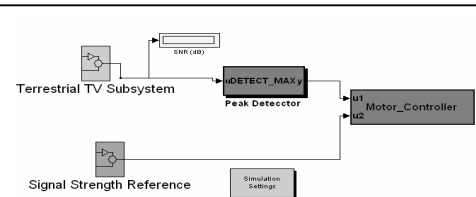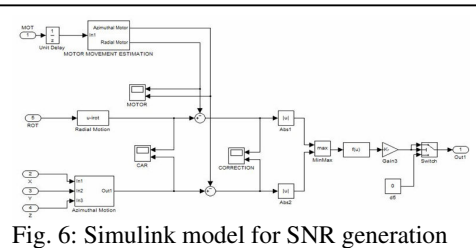Fig. 4b: Connection block diagram for the alignment of prototype Yagi-Uda antenna.

Fig. 5: Simulink model for motor control.

Fig. 6: Simulink model for SNR generation

Fig. 7a: Changes in direction of motion.

Fig. 7b: Changes in one direction.

Fig. 7c: Resultant position

Fig.8: Simulation of accelerometer.

Fig. 9: Simulink model of master control program.

Fig. 10: Vehicle moving in a virtual reality world.

Fig.11: Complete Simulation Model.

Fig. 12: Complete block diagram of the adaptive antenna assembly.

Fig. 13: Experimental setup for the alignment of prototype Dish antenna.

Fig. 14: Variation of SNR with vehicular motion (without corrective algorithm).

Fig. 15: Variation of SNR with vehicular motion (with corrective algorithm).

Fig. 16: Variation in SNR (dB) with Beamwidth.