# Communications System for a Solar Car

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## Abstract

This paper is intended to outline a project that will take place in order to produce a working interface and communications system for a solar car and its support vehicles. The system will be required to gather data from the cars sensors whilst displaying it to the driver in real time and transmitting the data to additional vehicles. Additionally voice contact is required between the vehicles. Progress information that has been collected must be stored and the appropriate web site updated when conditions permit. The specialized requirements of the computer software and hardware for the Team Gwawr solar car will also be considered.

## Keywords

Solar car; Solar Car Monitoring; VoIP; Wifi; IEEE802.11g/n; Propagation models.

## 1. Introduction

Glyndwr University have designed and built a Solar Car that it enters into Solar Challenges (Team Gwawr Web Site 2012). These run at different times of the year in different countries and a typical challenge is the one run in October 2011 across Australia from Darwen to Adelaide Figure 1a show the route (World Solar Challenge Web Site, 2012). In 2012 there is a similar challenge proposed in South Africa Figure 1c shows the route (South Africa Solar Challenge Web Site (2012). The normal configuration for the event is that the Solar Cars run with 2 support vehicles Figure 2, one running in front and the other following. This convoy can stretch over a distance of 1.5km. Clearly the support vehicles require information on the performance of the solar car. Usually the route is over an inhospitable environment so the solution to this requirement is not a simple “off the shelf” task.

Monitoring the operation of a solar car is a complex task since there is a requirement to keep the driver informed about the important parameters of the car whilst in operation.


Figure 1a: Route

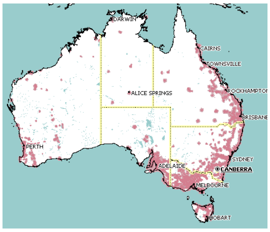


Figure 1b: Cellular coverage

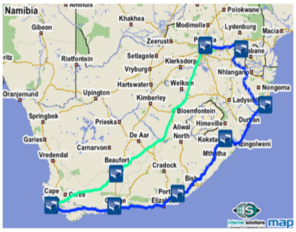


Figure 1c: South Africa 2012

This paper considers the display and communication of the parameters associated with the health of the car, analyses the requirements of providing this communication link and proposes possible solutions.

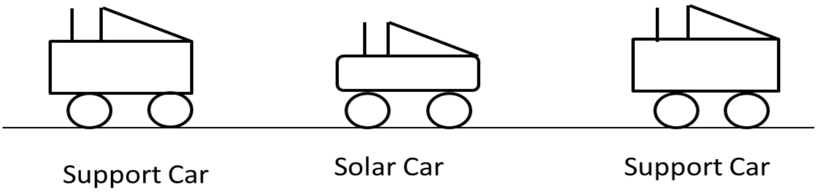


**Figure 2: Typical support scheme used during challenges**

## 2. Requirements of computer system

The project team associated with building and running the solar car are Engineers that do not have a Computer Science background. It was necessary to undertake an analysis stage to understand the interface between the car and the computer system but since the solar car is in a continual development environment the computer system requirements cannot be easily specified.

### 2.1. Physical Requirements

It is necessary to install much of the equipment within the solar car to prevent problems associated with support vehicles being out of communications range with the solar car. The external environment may be quite hostile due to the routes across deserts and the type of weather encountered, high and low temperature, varying levels of humidity. This will have a restriction on anything mounted outside the car e.g. wireless antenna. However the internal conditions are similar to a standard car since it is an enclosed space. There are some concerns which include heat, light, humidity, power and size. Additionally a great deal of thought needs to be given to both weight and power usage. The challenge usually involves driving in these hostile environments for up to10hrs / day.

### 2.2. Hardware Requirements

Clearly a low powered computer is required to run the software which should be reliable and run off the battery to reduce power taken from the solar car. It can be recharged every evening during the rest periods. Devices are needed to receive, store and display sensor information, provide feedback for the support cars so that they can update a website on the internet. From the visibility point of view the computer screens in the car is of great importance. Standard PCs devices could be used inside a sealed unit with appropriate vibration dampening. Similar PCs can be used in the support cars which would help with any maintenance problems. Techniques allowing peripheral visibility will enable the driver to assimilate complex information without looking away from the road. Displays in the dashboard may need hooding or can be inset into the dashboard in order to minimise direct sunlight exposure.

### 2.3. Data Collection and Display Software Requirements

There are numerous areas where sensor data can be taken to monitor the car's performance. Typical parameters that need to be monitored by both the driver and the support cars include the voltage, current and temperature of the batteries and the solar arrays. Other parameters include voltage, current temperature and frequency of the motor, the road speed and the surrounding environmental conditions e.g. temperature, wind speed etc. The data collected must be formatted and presented in a usable and intuitive way, accounting for the specific user interface and hardware limitations of operating the car. The driver should be able to select and view different parameters and be warned of any parameters that exceed or drop below predefined thresholds.

### 2.4. Communications requirement

A common feature of this type of application is associated with the type of area that is selected for the challenges. There is always a limitation on the route used which seems to have a lack of mobile networks both in terms of voice and data network. The sparse coverage necessitates the team to provide a private network so that reliable communication can be achieved (Telstra Com Web Site 2012).

The network will be required to provide the team with a reliable stream of data from the solar car along with additional voice communications. This will ensure that the support vehicles know the state of the solar car as well as the driver. A website will be updated to record the progress of the team whenever possible due to the limited and varying internet access this will include historic data of the route.

## 3. Possible Solutions

### 3.1. Data Collection & display Software

WPF and C# were used to communicate between applications by sending updates via TCP using the C# socket class. This can be used to synchronise applications across the three vehicles. Custom software was developed to meet the specific requirements of this project. To account for network instability, a robust system using Microsoft message queuing (MSMQ) was implemented in order to ensure data is not lost and prevent application crashes.

### 3.2. Communications Options

Any possible solution for the project must take into account the cost of the equipment and its availability since the team are in rural areas it must be reliable whilst still performing the necessary functions.

Where available mobile phone networks could be used to communicate with the internet, however due to the lack of availability this would not be suitable for the car data transmissions refer to figure 1b for typical network. WiMAX is a wireless standard that provides large area coverage at high speed which seems to be an obvious choice however due to the slow uptake of the technology the equipment is cost prohibitive for this project (IEEE Std 802.16h-2010). Wifi networks have been available for a number of years and have many consumer units available. This has driven down the cost of installing such a network however this technology does have limited range and was not designed for moving vehicles (IEEE Std 802.11-2007). Bluetooth specialises in low power short range communications which is suitable for in-car use but is unsuitable for the communications between the cars (IEEE Std 802.15.5-2009). Satellite communication was considered however the use of the dishes required to provide the communications link would provide a great problem when installed on the solar car due to the drag caused by wind resistance.

IEEE 802.11 will be focused upon for this paper because it is both easily obtainable and low cost however the range needs to be investigated further. In addition an IEEE 802.11 connection will be used from the support cars to upload the information to the internet. This upload will be carried out when and where appropriate, e.g. when passing through towns and in the evenings.

## 4. Investigation and Testing of Communications system

Standard wifi interfaces found in commercially available laptops was tested to find a value for the maximum distance that a signal could be detected as described in previous work (Davies J. N., Grout V., Picking R., 2008).

Measurements of the signal strength were taking at varying distance using Inssider (Inssider Web Site 2012), and the graph shown in figure 3 was drawn with dBs on the y axis (which is a log scale) and log distance on the x axis. Using a linear fit to the measured values the equation ($y = -23.293x - 45.695$) is obtained. Calculating the cut off distance using -85 dBs as the minimum strength then a distance of 46.8 metres is arrived at. Clearly this is not going to be suitable for this application therefore investigate into the gain of antenna was undertaken.

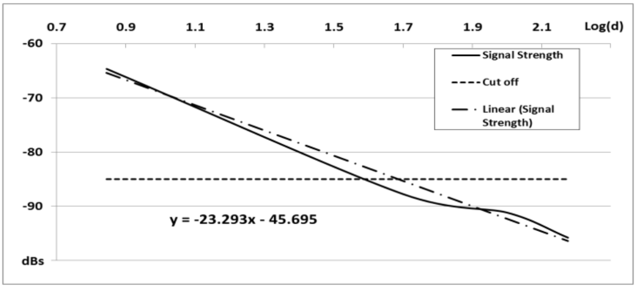


**Figure 3: Standard laptop to laptop signal strength**

### 4.1. Test Conditions

Much of the area that is going to be covered as part of the challenge is in free open space however there will be built up that will be passed through. As part of the tests it will be necessary to take into account urban as well as open areas. Most of the theory that has been put forward considers open free space so it is worthwhile recapping on this.

## 5. Theory of Transmission Signal Losses

As a receiver moves further from the signal source it receives less power because the signal is spread over a greater area, this is known as free space loss. Maxwell equations are a basis for this technology but there are many simplified models that have been used to enable calculations for the power received by an antenna under idealised conditions to be found. Friis Transmission Equation (Friis H.T. 1946) is one such model that has been used extensively for a number of years. The equation can be derived as such:

### 5.1. Friis Transmission Equation & Calculations

For an isotropic antenna for transmission and receiving in an open environment the power at the receiving antenna can be given by: $P_r = \frac{P_t}{4\pi d^2}$ where: $P_r$ = Received power, $P_t$ = Transmit power, d = Distance between antenna.

For an antenna with gain in the transmit direction this becomes: $P_r = \frac{P_t}{4\pi d^2} G_t$

Where: $G_t$ = Transmit antenna gain. As the receiving antenna will have a limited effective area the equation becomes: $P_r = \frac{P_t}{4\pi d^2} G_t A_{er}$ Where $A_{er}$ = Effective area of receiving antenna. The effective area for an antenna can also be expressed as: $A_e = \frac{\lambda^2}{4\pi} G$ Where: λ = wavelength. Therefore the received power is :

$$P_r = \frac{P_t G_t G_r \lambda^2}{(4\pi d)^2} \quad (1)$$

Usually the power and gain of an antenna is specified in db which is a log scale and so equation (1) becomes

$$Pr = Pt + Gt + Gr + 20\ Log_{10}\left(\frac{\lambda}{4\pi d}\right) \quad (2)$$

Typical values for laptops used in this application discussed in this paper are:- Pt = 15dbm, Gt = 2db = Gr since it is symmetrical, λ the wavelength = c/f where f = 2.4 Ghz and c the speed of light. Putting these values in equation (2) for a distance of50m gives a receive power level of -85.03dbm. Figure 4 shows the graph created from the calculation and compares it with the measurements shown in figure 3.

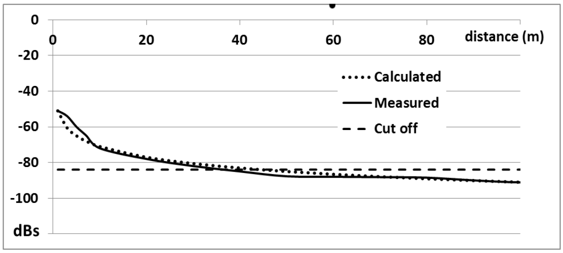


**Figure 4 Calculated v Measured**

From these graphs it can be seen that there is a close correlation between the calculated and measured values and the cut off distance of around 50m is confirmed.

Equation (2) can be re-arranged so that the gain require of the antenna for a given distance can be calculated - $2G = Pr - Pt - 20\ Log_{10}\left(\frac{\lambda}{4\pi d}\right)$

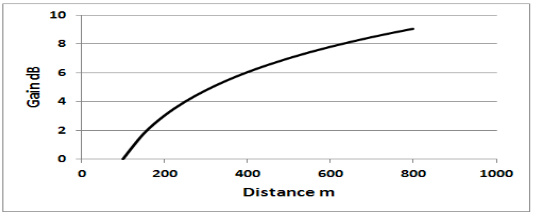


**Figure 5 Gain require of antenna to achieve distance**

## 5.2. Terrain

Normally for wifi networks operating at 2.4 Ghz the issue of operating in a mobile environment is not considered since the distance cover is usually within a radius of 50m. However in this application there needs to be an investigation into the effect of motion and environment.

There are a number of wireless propagation models but they are all empirical in nature. They have been produced to help understand the cell phones applications unfortunately most of the models developed do not apply 2.4GHz. Empirical models do not describe the exact behaviour due mainly to the problem of specifying accurately the environment under which it is being used. To this end there are a number of different models intended for use in different environments. One of the authoritative works in this area was carried out by Okamura in Tokyo city (Okamura, Y. et al. 1968). This was improved by Hata who added components for predicting the behaviour in city outskirts and other rural areas (Hata, M. 1980). There are numerous other models but they are based on this initial work. The Hata model for Suburban Areas is given by: $Lsu = Lu - 2\left(Log\frac{f}{28}\right)^2 - 5.4$. Where, LSU = Path loss in suburban areas. Unit: decibel (dB), LU = Average Path loss in urban areas. Unit: decibel (dB), f = Frequency of Transmission. Unit: megahertz (MHz) and for open areas is given by: $Lo = Lu - 4.78(Logf)^2 + 18.33\,Log\,f - 40.94$. Where, LO = Path loss in open area. Unit: decibel (dB), LU = Path loss in urban area. Unit: decibel (dB), f = Frequency of transmission. Unit: megahertz (MHz).

## 6. Measurements

So by using antenna with a higher gain at the receiver and transmitter it is possible the required distances will be obtainable. A series of measurements were undertaken to see how the manufactures antenna agree with the theory. USB 802.11n adapters that have an N type plug can be used to test out antenna of differing gains. Antenna to be tested will be the 3 dBi antenna that is supplied with the adapters. The following three antennas will also be used: Sitecom 5 dBi WL-030, Sitecom 7 dBi WL-032, Sitecom 10 dBi WL-031 (Sitecom Web Site 2012),

The first test that was undertaken was to see if there was a difference in the attenuation at each channel that is available to wifi. Results showed that channel 8 should be avoided.

### 6.1. Isotropic antenna

An isotropic antenna is one that radiates equally in all directions which is ideal for this application.

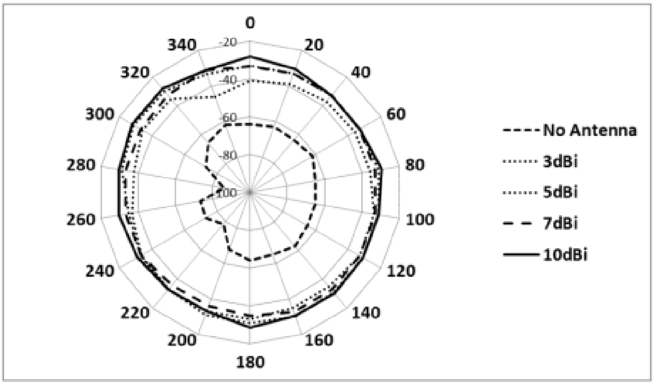


**Figure 6: Polar plot of signal strength for antenna with different gains**

However in reality this is not possible to build so careful measurements were taken at differing angles to enable a judgment to be made about the suitability of the antenna to be used. Figure 6 shows the results and it can be seen that any of the added antenna perform much better than the standard laptop. All these measurements were taken using the same equipment changing just the pole of the antenna and a distance 10 metres was used.

### 6.2. Signal strength versus distance

Test when then undertaken on a quiet, straight road to obtain the relationship of the signal strength at various distance from the transmitter. The laptop containg the usb IEEE802.11n interface was placed on a tripod and with the use of Insider the signal stength in dbs for was recorded. This was then repeated using anteanna with differing gains. The results can be seen in figure 7. It can be clearly seen that distances of 800 metres can be easily achieved. Its not possible to fit a straight line to these graphs since the plot is actual distance not on a logarithmic scale

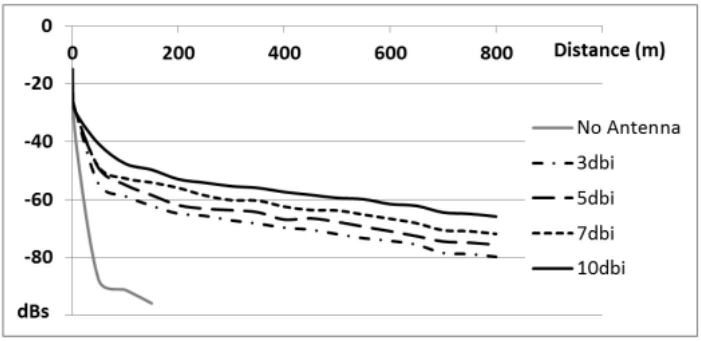


**Figure 7: Signal strength for antenna varying with distance**

### 6.3. Effect of speed of movement on signal strength

Due to the nature of the application an investigation into the effect if the signal strength whilst attached to a car travelling at speed. The intention is to mount the antenna to the external of the car to avoid problems associated with signal absorption by the carbon body. This antenna will then screw into the receiver which is mounted in the bodywork of the car immediately below.

An extended usb cable will then be used to attach the receiver to the laptop. By doing this it reduces the attenuation since the analogue signal is converted at the entry point. A series of tests were undertaken the maximum speed attempted was 70mph which was slightly beyond that expected for the solar car. These tests showed that there is little difference in the signal strength over the range 20 to 70 mph.

## 7. Voip Considerations

One of the major requirements of the system is to have the ability of voice communications between the cars. By referring to figure 1b it is clear that this can not be reliably provided by any of the standard cellular phone networks. The communications network setup between the cars is based on the IP protocol and therefore voice over IP (VoIP) is an obvious choice. By restricting the voice network to just the cars it means that a very small system can be used. There would be no need for a PBX and so one of the VoIP systems used frequently by the Games fraternity could be adopted. A number were investigated but Teamspeak (Teamspeak Web site 2012), and Mumble (Mumble Web Site 2011), were chosen as having the most appropriate features. The tests where done by using a standard laptop fitted with a combined headphone and speaker. A MP3 player was strapped to the microphone at one end and the recorded speech was judged by listening through the headset at the other end. This is a bit subjective since it relied on the person's objectivity but it ensured consistency of the transmission. An analysis of the results showed that low quality setting on Mumble is going to give the best performance.

# 8. Conclusions

The solar car application is quite unique in its requirements due to the challenges that are defined however there are likely to be a number of other applications with similar problems where vehicles travelling in convoy need to communicate. One of the major problems associated with this project was the un-availability of standard network services and therefore a novel approach had to be sought.

## 8.1. Results obtained

The analysis of geographical and testing conditions showed that the wireless technologies are the best solution for doing the monitoring of solar car characteristics. Custom built network structures were dismissed due to reliability and the ease of replacement of faulty equipment. Since WiMax technology is still being developed the availability of equipment is low and the cost is high so it was decided that the best choice is an IEEE 802.11n. Clearly IEEE 802.11n does not cover the distances required so it was necessary to do further investigations. Theoretical calculations showed that an antenna with a gain of 10db a distance of up to 800 metre could be achieved.

Another requirement of the project was to enable the cars to travel at speeds up to around 50mph in convoy. Further experiments showed that the effect of speed is very little and so the speed of cars is not a critical factor for the wireless network.

Due to the lack of network services it was also necessary to provide a VoIP system. to enable the drivers to communicate in remote areas. A number of VoIP systems were investigated the basis of the decision was that it needs to be small, compact and can be run on a low power processor. Experiments were carried out with Teamspeak and Mumble which showed that Mumble in low-quality settings was the best match to the requirements.

## 8.2. Future work

For the future it would be useful to do further work on the models associated with the surrounding environment. Clearly the vehicles will travel not only through desert like conditions but also through towns, small villages, forest areas and mountainous regions. The models would help confirm the operation in these environments. A justification for the use of a simplified VoIP application will be the subject of a future paper.

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