論 文 内 容 の 要 旨

Introduction:

Radio observation of meteors can be a rich source of information on the deep space components and mesospheric conditions for professionals, as well as a live experience for amateurs interested in listening to space continuously. Professional observers usually use satellites or large ground radar systems of high cost to detect the largest amount of meteor records possible. On the other hand, amateurs use the low cost classical basic setups to observe meteor echoes as a hobby. In between them there exist researchers at low budget institutes trying to use the classical basic setups for educational and scientific purpose. The Kochi University of Technology (KUT) meteor observation system provides a model for making the most of the basic instruments setup in three different research features based on the forward scattering phenomena:

1. Astronomical purposes.

2. Upper atmospheric science.

3. Communications.

The target audience for this research is normally the technology institutes wishing to start space observation activities at low budgets in Africa, Latin America or Middle East.

1. Astronomical observations:

The KUT system has gradually developed from the basic setup configuration to an interferometric direction finding configuration, then finally to a multi-site meteor path determination setup. The primary target is to develop a mechanism for determining the trajectory and origin of every meteor detected by a received echo signal. The design of the system is based on the classical setup of forward scattering systems as described in the International Meteor Organization (IMO) website (Figure 1). To provide useful astronomical results, the research focused on automating the observation process through software developments. The developments resulted in an automated observation process for the following parameters:

1.1 Meteor echo counts and durations:

The software HROFFT (Ham-band Radio meteor Observation Fast Fourier Transform) has been developed in Japan to provide spectrum images of meteor echo signals every 10 minutes. The image processing software MEC (Meteor Echo Counter) was developed at KUT to scan these spectrum images and generate text files of meteor counts and durations automatically.

Meteor echo counts and durations are considered the most basic parameters used to observe meteor showers activities.

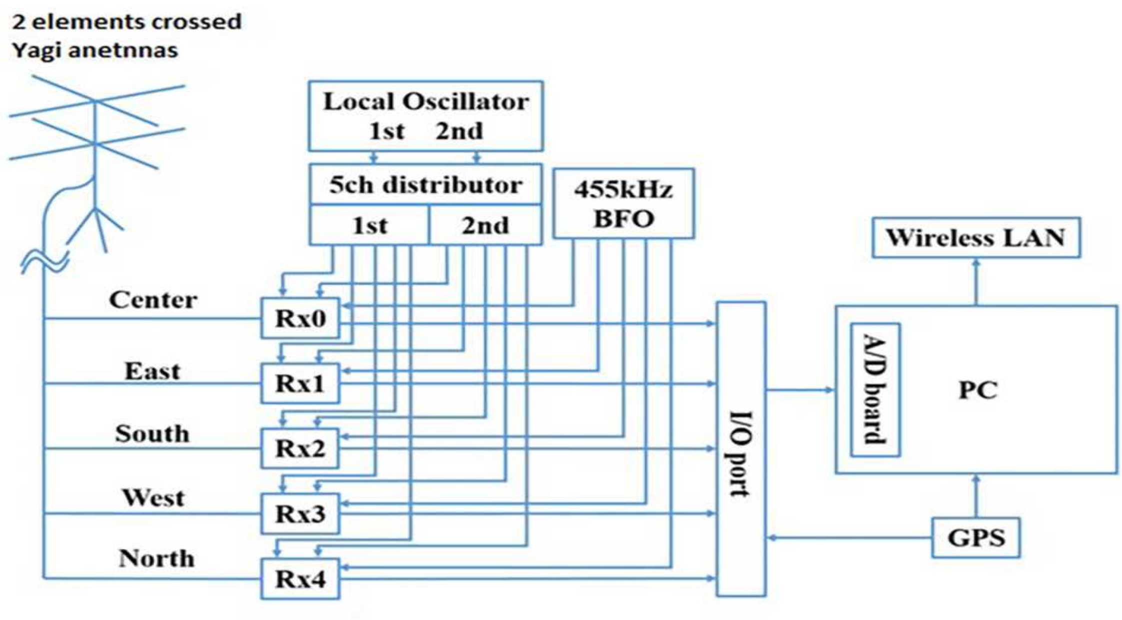

Figure 1 Interferometric direction finding setup at KUT campus

1.2 Meteor Echo Directions:

The setup of the 5 channels receiving system in figure 1 allows the determination of the meteor echo directions through interferometric analysis. The interferometer configuration is shown in Figure 2 and is considered the most common and efficient configuration among observers worldwide.

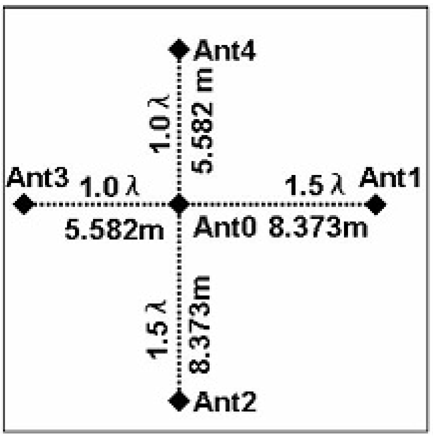

Figure 2 Interferometric configuration of receiving antennas at KUT

To automate the direction finding process, two software applications HRO_IF_V2 and HRO_IF_VIEW were developed to automate direction finding of every meteor echo .The direction (azimuth and elevation) information was observed with higher accuracy for meteor echoes with durations longer than 3 seconds. Meteor echo direction is considered the basic element required towards meteor trajectory and velocity determination. The graphical output of the software HRO_IF_VIEW is shown in figure 3.

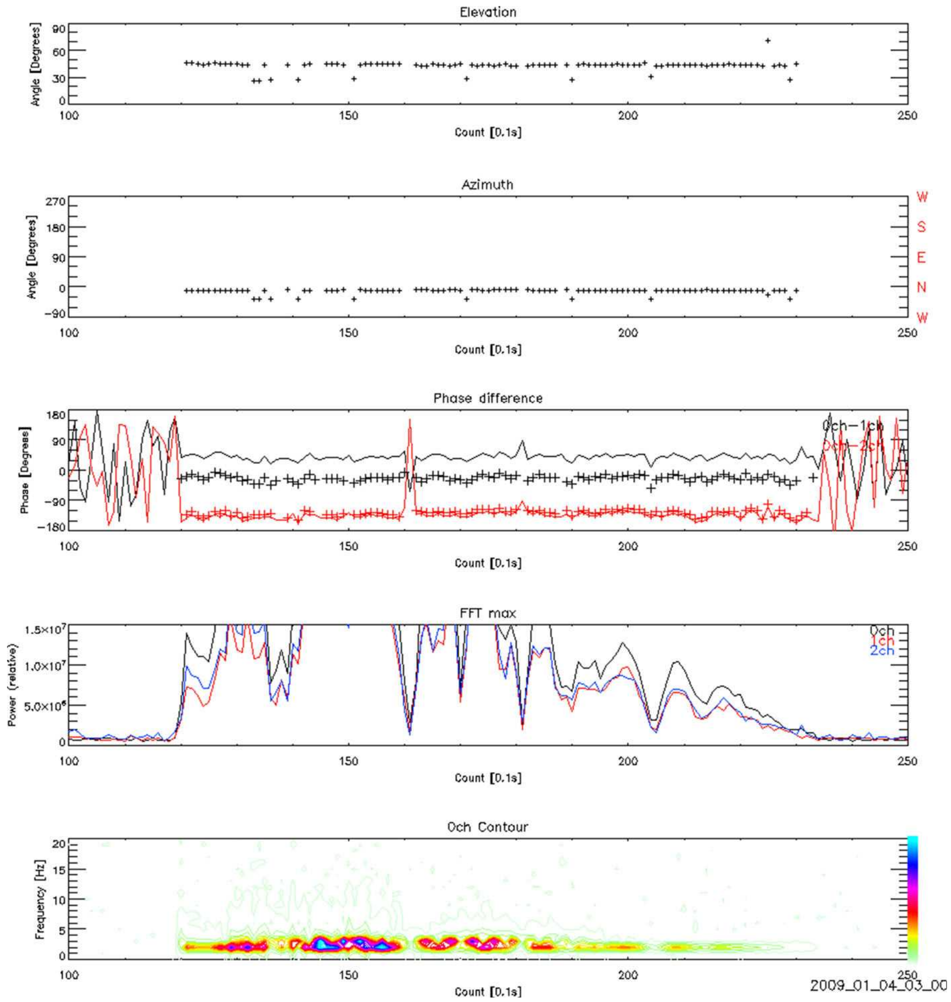

Figure 3 HRO_IF_VIEW software output showing Azimuth and Elevation angles at the top 2 panels

1.3 Meteor Echo Trajectory and Velocity:

The last step towards finding the origin of every meteor echo detected is through trajectory determination. Two additional remote sites were added at distance of around 15 km from the central site. The time difference of same meteor echo detection at the three receiving sites allows the determination of trajectory and velocity of meteors under certain assumptions (Figure 4). The software HRO_TRA was developed to automate trajectory and velocity observation for undersense meteor echoes only because of the determined signal profile of this type with impulsive rise at the beginning of each echo.

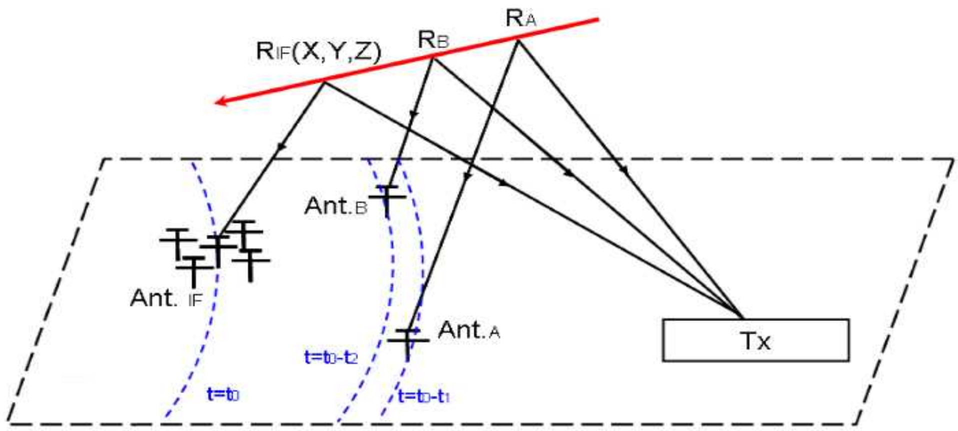

Figure 4 Meteor trajectory determination concept using multiple receiving sites with a central interferometer.

The determination of the origin of every meteor echo could provide astronomical information on the characteristics of comets and other sources of meteoric objects in the deep space through statistical analysis. Due to the long time taken in the system setup and software developments, statistical analysis were not performed at KUT on the large scale. However, the methodology description were published and the software was made free to encourage other researchers worldwide perform further analysis.

2. Upper atmospheric science:

The ionized meteor trails generated during the entry of meteors to the Earth's atmosphere at a high velocity is considered as an indirect source of information on the mesospheric conditions. The role of the mesospheric secondary ozone layer in oxidizing the ionized trails was proposed to be the primary cause of the trail removal below the 95 km height. The relationship between the ozone deionization process and the overdense meteor echo durations was further developed to an ozone concentration observation method. The method uses the knee-shaped curve of the statistical cumulative logarithmic plot of the meteor echo counts versus echo durations during a certain period. As the mesospheric ozone is inversely related to the solar activity, the varying position of the knee during the daytime and night time, seasonally or annually can be an indirect observation unit for the mesospheric ozone concentration and the solar activity level.

The cumulative meteor echo duration distribution of two distinct meteor showers, the

Perseids and the Geminids, were analyzed over 10 years using the KUT observation system and the knee position in each shower was observed. The knee duration position at which a drop in the number of long overdense meteor echoes starts differed by around 30 seconds between the two showers (Figures 5 and 6), which can be indicative about the ozone concentration impact on the two meteor showers of different altitude, velocity and occurrence time.

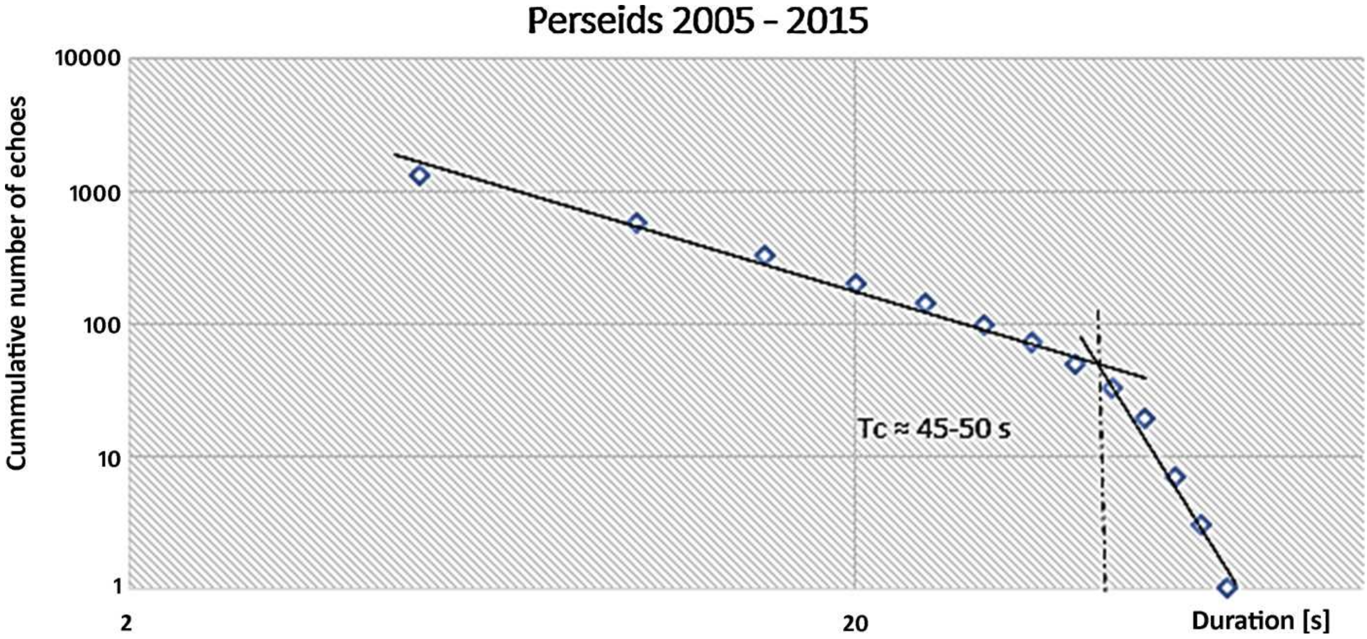

Figure 5 The duration distribution of the Perseids overdense meteor echoes from 2005 to 2015.

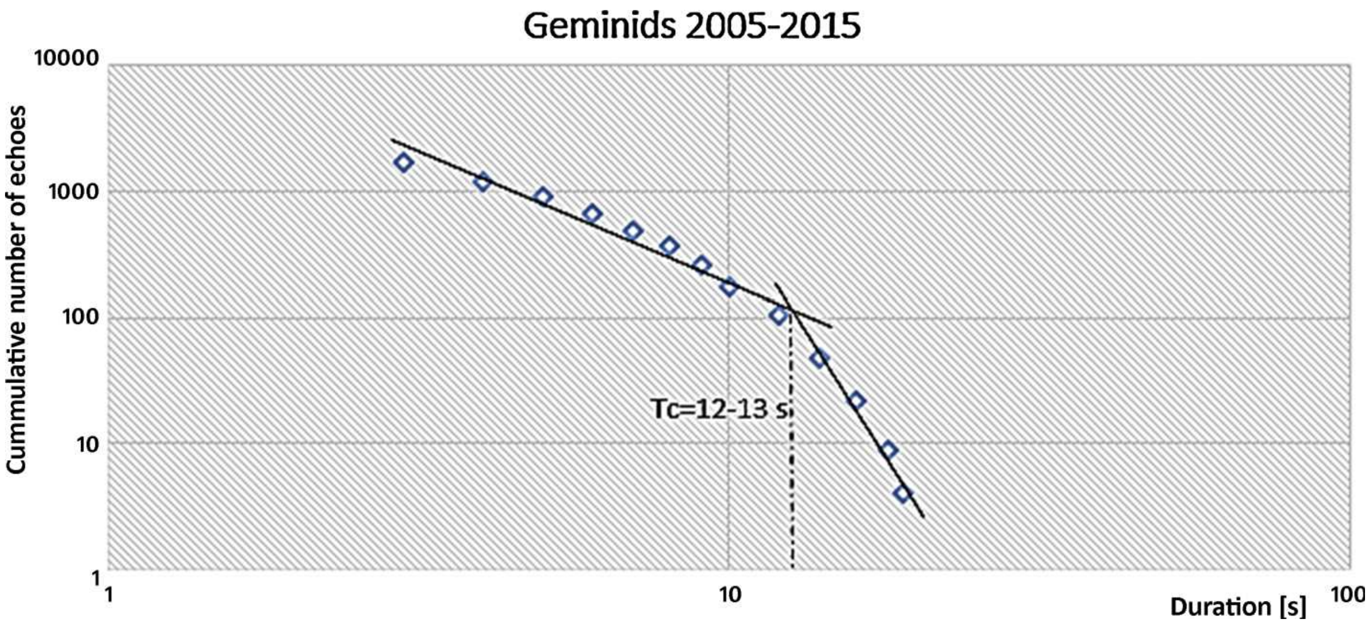

Figure 6 The duration distribution of the Perseids overdense meteor echoes from 2005 to 2015.

The discrepancy in the knee position agrees with the impact of the aforementioned distinct characteristics of the two showers. The velocity and height range of the Geminids was agreed by both optical and radio observations to have lower levels than that of the Perseids. Therefore, meteor ionized trails of the Geminids could be more affected by the secondary ozone layer maxima below 95 km. Also, the depletion of the ionized trails of the slower Geminids meteors in the atmosphere is higher than that of the faster Perseids meteors and therefore the loss of the electrons is higher, thus moving the knee position of the Geminids to an earlier stage.

The observation of the mesospheric ozone concentration variations could allow indirect observation of the 11-years solar cycle activity. The annual data records however were not complete for all years and for some years were totally missing. To observe the 11-years solar cycle activity, two years were selected that has full uninterrupted data records with 5 or 6 years separation. The knee positions of the Geminids 2006 and Geminids 2011 representing low and high sunspot number progression levels are compared in figure 7. The knee position for Geminids 2006 is observed at duration range of 8 ~ 9 seconds which is less than the average Geminids knee durations. This although agrees with the impact of lower solar activity and the increase in the ozone concentration level in 2006, there can be other factors impacting the radio detection rates for the two single years such as the varying flux nature of the Geminids shower itself. The continuous annual analysis of the Geminids duration distribution for the whole 11-years solar cycle becomes essential to confirm the solar cycle activity observation by this method.

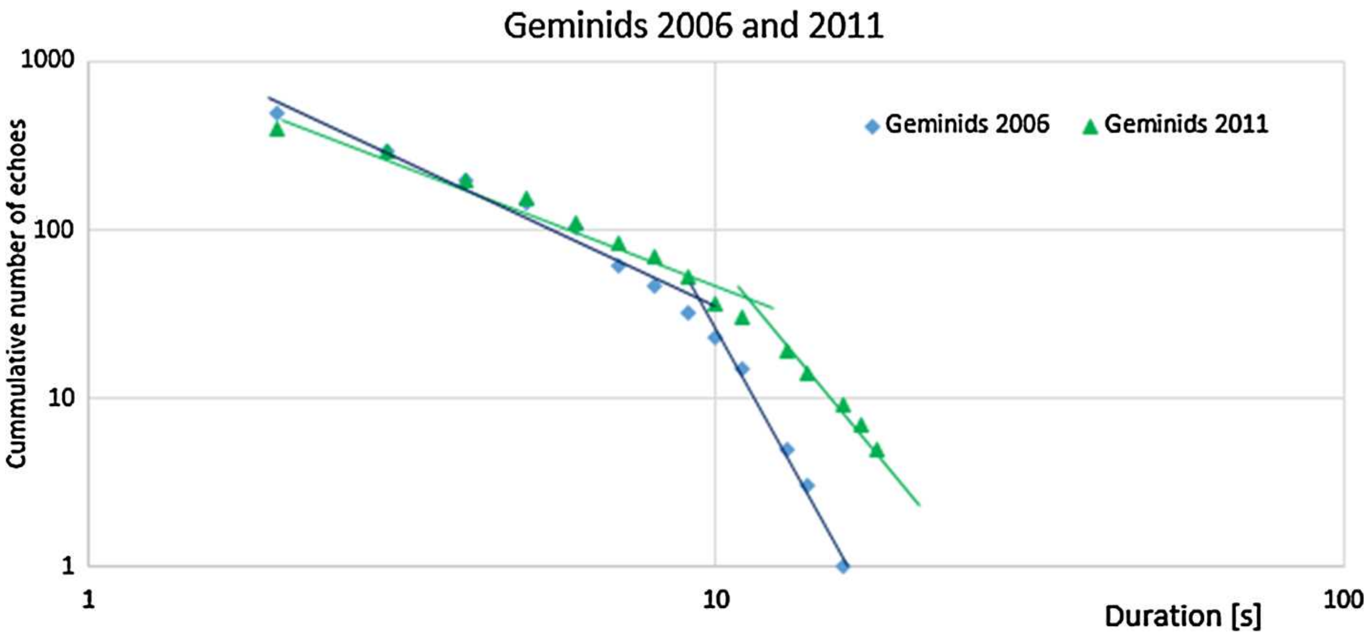

Figure 7 The duration distributions of the Geminids 2006 (minimum solar activity) and Geminids 2011 (maximum solar activity).

3. Communication:

Meteor Burst Communication (MBC) has been used limitedly in the recent decades due to the technology revolution of the mobile and satellite telecommunication networks. However, there are still situations were MBC can be the optimum solution in terms of availability and cost. Based on the ongoing astronomical and scientific research on meteors at KUT, information on usable meteor trails for MBC is utilized to research the potential of using MBC in the telecom Internet of Things (IoT) or Machine to Machine (M2M) scenarios. Astronomical information on the meteor echo directions allows estimating the locations of hot spots in the sky to direct the transmitting antennas to. Also, the scientific analysis of the mesospheric conditions and solar activity through the forward scattered echo signals duration analysis allows the estimation of the best times for transmission.

The MBC research carried out at KUT targets low data rate applications in large desert areas such as the situation in Egypt where the mobile network covers only the populated Nile Valley area. Currently, the distant communication in these desert areas rely on the expensive satellite coverage which is not convenient for continuous transmission applications such as M2M telemetry and vehicles tracking. Another applicable situation is in Japan where the mountain terrain nature of the land prevents direct radio communications while the mobile networks are suspect to damage during natural disasters. The MBC although is a good candidate for replacing satellites in these applications, the large size of the common MBC systems doesn't provide practical solutions for the mobile applications. This has raised another design consideration in our research to minimize the size of the system to be attractive for practical use. To achieve this, initially we changed the frequency used from 53.75 MHz to 144 MHz to decrease the antennas size. Although this will normally cause less probability to hit meteor trails but the practical value added benefits from the system mobility makes it worth trying. A compromise is then included in the research between the size, cost and performance of different solutions. Although the cost benefits are already maintained by replacing satellites with a natural phenomenon, further cost reduction was done by minimizing power of transmission to be as low as 10 W.
Lastly, another design consideration was to automate the transmission process through software developments.

The MBC research at KUT is currently in the testing phase, an M2M telemetry scenario was chosen for testing. The scenario is for vehicles transporting pharmaceutical products for long distances in the desert and it's required to track the temperature of the products regularly and automatically every half an hour at most (Figure 8). Recently the radio transceivers companies added new features that enables the interface to Android devices. This has matched our requirements as the Android devices has built-in sensors for temperature measurements. An Android software application is under development to automate the transmission of the built-in sensor readings from the Android device in the vehicle through the radio transceiver. The search of a usable meteor trail is the most challenging task in the process. Previously, MBC systems used continuous probe signals to find the meteor trail and then start transmission accordingly. We have chosen the simpler approach of directly transmitting the sensor information repetitively and randomly without waiting for a response. The small packet size containing the simple sensor data can already resemble a probe signal. The software is designed to attempt transmission every 30 seconds to overcome the low probability of hitting a usable meteor trail during half an hour. While this may impact the power source used, future design would consider the use of solar cells on top of the vehicles for power generation with plenty of sunny times in the desert areas.

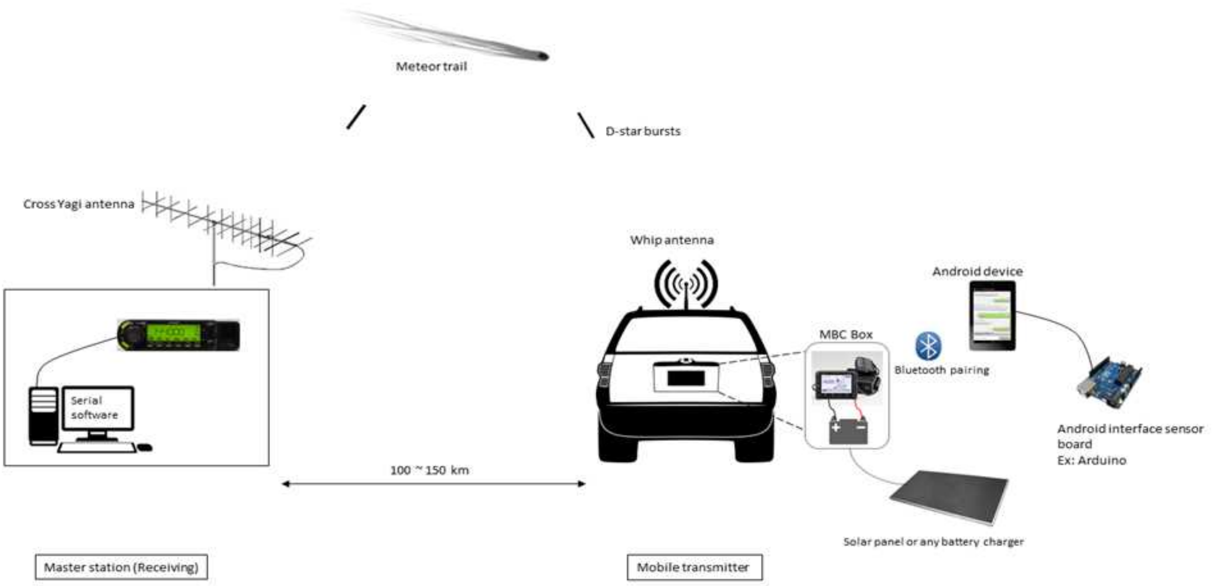

Figure 8 The MBC experiment configuration at KUT

Summary

The forward scattering of signals from meteor trails is a natural phenomenon that can be used for various purposes. The theme of the thesis is a broad analysis on the possible usage in astronomy, atmospheric science and communication. The maximum benefits on each of these topics were not achieved and we let the door open for researchers at low budget institutes to perform further specific researches on the three topics.

The astronomical meteor observations and the atmospheric sciences are common research features among meteor radio observers worldwide. However, the automated observation system through software is considered the point of strength at KUT. The concept and the system design configuration of the MBC through Android devices has been purely generated at KUT. Although no solid results are available yet, the KUT team is convinced -based on the scientific background- that it could succeed in providing useful communication alternatives