Technical Report

Project AECDIMEEIA

ADS-B-Enabled Cheap Decentralized IoT Mesh Enhancable Embedded Information Acquisition

基于 ADS-B 的低成本去中心化可优化物联网嵌入式信息获取系统

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The author’s words

The author would like to appreciate all reviewers and experts for their patience in advance (hopefully so) to read this report. Besides, the author would like to thank Mr. Yuhai Cao for the wonderful logo of this project, and Mr. Hanyu LIU for proofreading. The author would also like to thank Ms. Liyan Jing for providing insight to the topic.

The author has tried his best to make the report more interesting to digest, and to fully understand the working principle of this project it is necessary to read through it. If EE is not of your particular interest, please jump to page 5 to start from working principles. The most important points are marked in red, which will also be summarized in a separate file.

1. Introduction

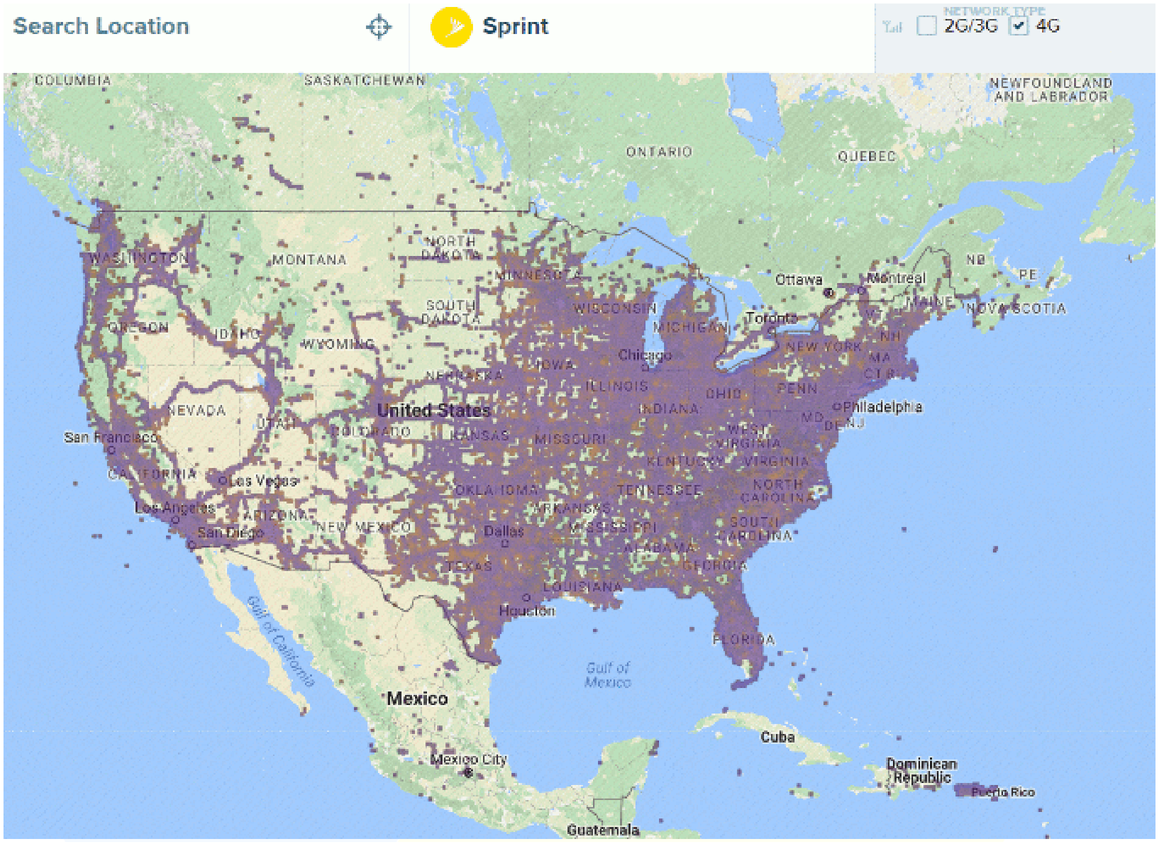
As digitalization of the world proceeds down the track, the modern society, and especially urban areas, are gradually embracing the newer and fancier technologies for better city management. Nowadays even the old grandma talks about 5G and AI on the table of Christmas dinner. Information seems to be infiltrating everywhere via smartphones and digital terminals. When people talk about doing something, they take it for granted to “develop an app”, or “use machine learning”, or do some other fancy tricks. City people lives in a bubble, which shades them from outside.

On the other hand, however, the reality is cruel. Outside the city the accessibility of information is very limited, especially to farmers. Although there have been some trials by countries like China to utilize the current 4G infrastructure on the high-speed train (HST) system to distribute the information to the farmers along the rail, this is not generally practical to most countries, and it doesn’t work as well as expected due to clearance areas along the rail. Even if for countries with relatively developed HST system like Japan and Germany, due to the different hub-and-spoke developmental strategy, the coverage areas will be very limited.

Using smart phone to deliver information is based on an even more fundamental assumption: the farmers have a decent smartphone (which costs at least around $100) and a reliable internet connection, which is usually not the case at all. For farmers in extreme conditions, such as extreme temperature and humidity, proximity to war zone, and extreme poverty, a working smartphone is in many cases only a dream. Literacy rate also causes problem. In China and many countries, many old people don’t know how to read or use a smartphone. They need their kids and grandkids to teach them step by step and remember by heart how to use the phone. But those old citizens comprise of the majority of farmers and rural residents, which is an inevitable problem.

Besides, for countries with poor mobile network infrastructure, such as Germany (although they are always trying to be better), sometimes it is even not possible to join the mobile network to give a phone call, not to mention mobile data. There has been news that in a German village, the only place with mobile network coverage is the cemetery. That’s not very attractive, isn’t it?

If you feel like to claim that Germany is an exception...


Search Location
Sprint
NETWORK TYPE
2G/3G
4G
COLUMBIA
SASKATCHEWAN
NEWFOUNDLAND AND LABRADOR
ONTARIO
QUEBEC
NORTH DAKOTA
WASHINGTON
MONTANA
MINNESOTA
Ottawa
Montreal
NB
PE
SOUTH DAKOTA
WISCONSIN
MAINE
NOVA SCOTIA
OREGON
IDAHO
WYOMING
MICHIGAN
Toronto
NEW YORK
NH
IOWA
Chicago
MA
NEBRASKA
CT RI
ILLINOIS
OHIO
PENN
NEVADA
United States
INDIANA
Philadelphia
UTAH
MD
DE NJ
San Francisco
COLORADO
KANSAS
MISSOURI
WEST VIRGINIA
KENTUCKY
VIRGINIA
CALIFORNIA
Las Vegas
OKLAHOMA
TENNESSEE
NORTH CAROLINA
Los Angeles
ARIZONA
ARKANSAS
San Diego
NEW MEXICO
Dallas
MISSISSIPPI
SOUTH CAROLINA
ALABAMA
TEXAS
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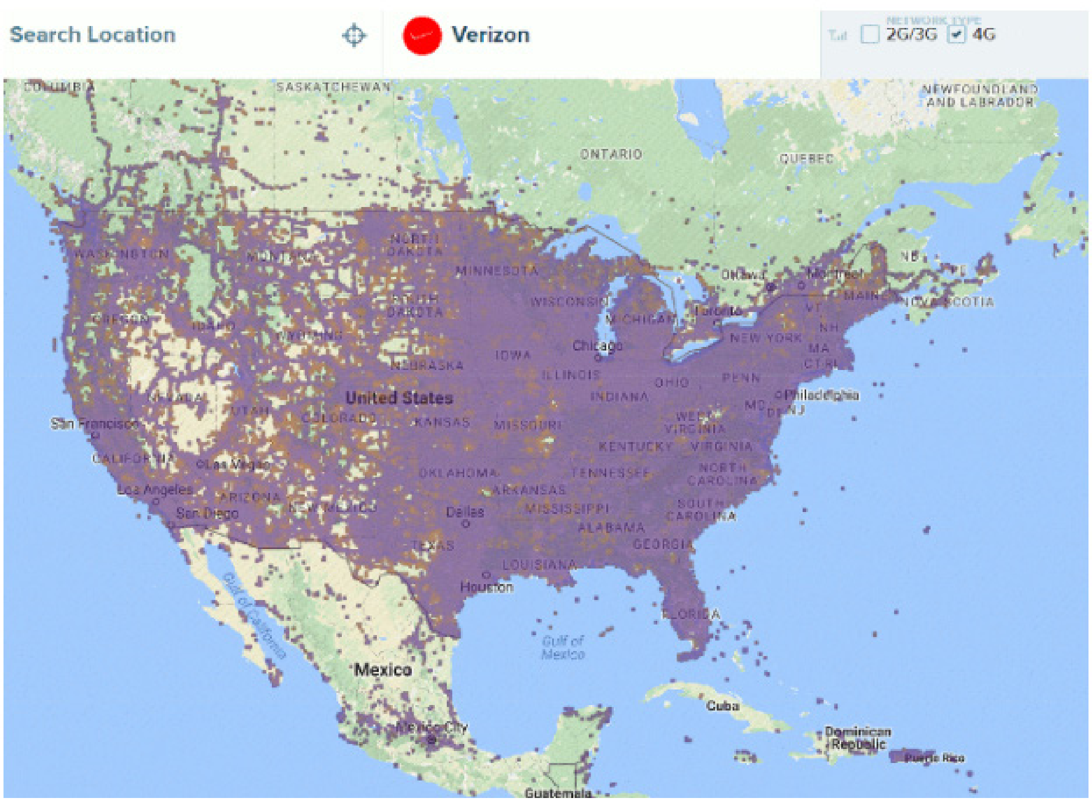
Gulf of Mexico
Mexico
Cuba
Mexico City
Dominican Republic
Puerto Rico
Guatemala


Search Location
Verizon
NETWORK TYPE
2G/3G
4G
COLUMBIA
SASKATCHEWAN
NEWFOUNDLAND AND LABRADOR
ONTARIO
QUEBEC
NORTH DAKOTA
WASHINGTON
MONTANA
MINNESOTA
NB
Ottawa
Montreal
SOUTH DAKOTA
WISCONSIN
MAINE
NOVA SCOTIA
OREGON
IDAHO
WYOMING
MICHIGAN
Toronto
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NEW YORK
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San Francisco
COLORADO
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MISSOURI
WEST VIRGINIA
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CALIFORNIA
Las Vegas
OKLAHOMA
TENNESSEE
NORTH CAROLINA
Los Angeles
ARIZONA
ARKANSAS
San Diego
NEW MEXICO
Dallas
MISSISSIPPI
SOUTH CAROLINA
ALABAMA
GEORGIA
TEXAS
LOUISIANA
Houston
FLORIDA
Gulf of California
Gulf of Mexico
Mexico
Cuba
Mexico City
Dominican Republic
Puerto Rico
Guatemala

This is the mobile coverage of two US ISPs. The situation is more or less the same for all other ISPs in the US, and you can clearly see that the areas left out is exactly rural and less populated areas. Montana is almost unserviced the entire state in Sprint network. (See, sometimes, network coverage is not even available at cemeteries...)

Therefore, under these real restrictions, it would be much more practical to move the eyes away from smartphones for a while and think for another way out. Smartphones are good, but we need to make sure we can still do something without it. Therefore, during project AECDIMEEIA (reads: academia) and in this technical report, a practical solution that can be immediately implemented was researched, developed, and documented.

2. Technical background

It is of great importance to introduce the technologies used during the project. Let's start from the core: the ADS-B system. ADS-B, automatic dependent surveillance-broadcast, is a technology that enables the aircraft to communicate its information via broadcasting to other receivers. It works on 1090MHz as a replacement for the secondary surveillance radar and is much more important in future aviation, as "interrogation" is no longer necessary, and therefore other aircrafts and ground receivers can listen without any need to dissipate their power into the air as a signal.

Although the guidance standard, DO-260A/B, have been released for quite a long time, it did not arouse much interest previously, as one major problem is that ADS-B was an optional equipment by that time, and it was kind of bulky and heavy to be honest, which means it was economically not so favorable.

But in recent years, governments around the world have agreed to force it to be mandatory. By January 2020, FAA will mandate all aircrafts entering most of the airspace of US, one of the most important potential market, to be equipped with ADS-B system, removing the largest barrier for the mass application of this solution. Some other governments and organizations have already taken their actions and carrying out researches based on ADS-B, e.g. the EU's SESAR and ICAO's ASBU.

Meanwhile, as electronics were constantly being developed and evolved, it is practical and now also a common practice to integrate the ADS-B system into the Mode-S transponder, further reducing the weight penalty on the aircraft performance. ADS-B is also extremely popular, and more or less a must, among aviation enthusiasts. There have been many reports performance-wise, claiming that aircrafts as far as 270km away can be properly identified and deciphered.

It does not require any sophisticated hardware either. ADS-B by standard is unencrypted. The information can be easily interpreted from the received message. A microcontroller, a spring antenna, and a battery will be sufficient to do the job, making it extremely fit for low power consumption and low-cost requirements.

It's also important to know about transmission protocols: Bluetooth and 802.11. The newest Bluetooth 5.1 protocol supports network mesh at its very basis, and also physical layer low energy (BLE) characteristics, where power consumption can go as low as 0.01W. Bluetooth also supports long distance transmission as far as 1.6 km on cheap commercial products, although at a low bit rate. However, it is already sufficient for the need of control purposes.

The 802.11 family of protocols, commonly known as WIFI, can serve various scenarios with different bit rate and range. There are also cheap commercially available products with effective range of 1.5 km, and some very special products with range 20 km. With that being said, the line of sight should be guaranteed. Another particularly promising system is LoRaWAN, whose patent holder claimed that a maximum operation range of 10 km can be achieved in rural areas, with a trade-off of data rate.

Finally, it's also advisable to know about embedded systems. Embedded systems utilize the offerings of modern electronics, namely SoC, SMD and PCB. The entire system is integrated in one single chip, dramatically reduces system power consumption and size.

3. System design

3.1 Code scheme design

By now the general concept of this solution can be introduced. The solution works as the followings: On the air side, the aircraft receives the weather forecast and market information received from the datalink, RF communications, or satellite mission load, which was uplinked by participating organizations. Using existing ADS-B equipment, the aircraft broadcasts the information to the ground receivers at the farmer's phone or home. On the ground side, the local weather stations collect the data of localized sensor and monitoring equipment and transmit it in the same ADS-B standard. Then data is interpreted to let the farmers aware of the weather information or market prices. The receiver can then display the information and make decisions based on that.

But it's always easier to say than to do. To properly introduce the system, we need to start by digging further into the technical details. The modern ADS-B system uses a 112-bit-long code (message), and has the standard structure like below:

```
+--------+-------+--------------+------------------------+---------+
| DF 5 | CA 3 | ICAO 24 |        DATA 56        | PI 24 |
```

Here, DF 5 denotes the downlink format which occupies 5 bits. For standard ADS-B message via mode-S transponder, the DF value is typically BIN 10001 (DEC 17), and such system is typically denoted as DF-17 system. Currently, DF-0/4/5/11/16/17/18/19/20/21/22/24 are used, with DF-22 chosen for military application. DF-24 in particular serves for extended codeword, which will be addressed later. The CA code works as an additional identifier, and the last 24 bits are parity bits for cyclic redundancy check, which are not the primary concern of this project.

Here, the ICAO 24 is used to identify the aircraft that transmitted the signal. Every aircraft is assigned a HEX code by ICAO. For example, the code 3C4B32 corresponds to 001111000100101100110010, which is the B747-830 operated by Lufthansa under registration D-ABYR (named "Bremen"). By making use of these 24 bits, regulatory authorities can force the device to accept only the data provided by certain aircrafts, ensuring the network safety.

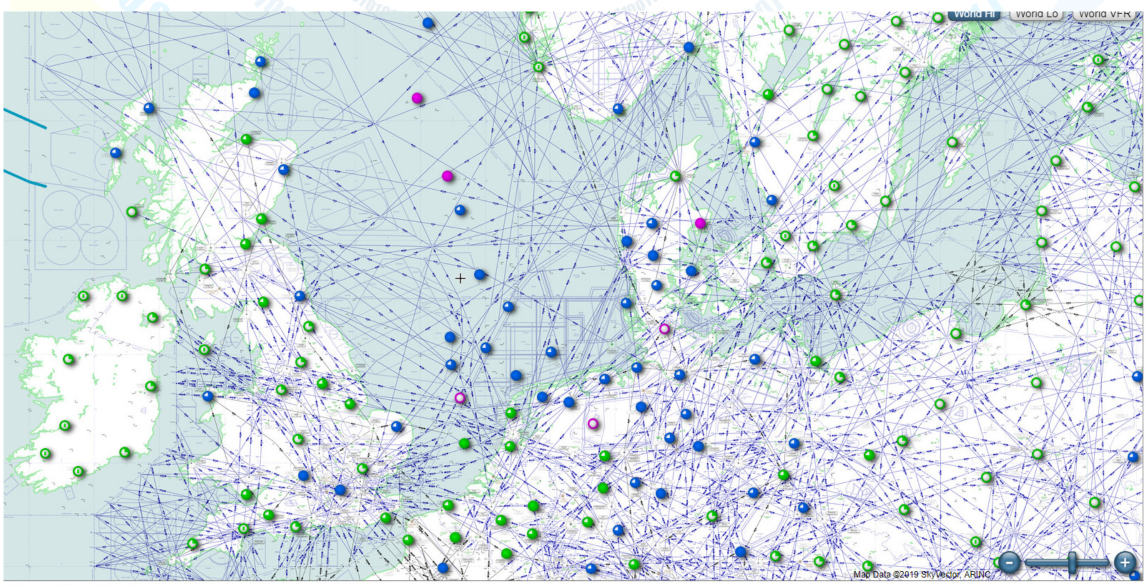
The main part of the message is the DATA part, which occupies 56 bits. In DF-24 system it even occupies 80 bits. This is what we manipulate. ADS-B uses a special scheme to report the location of the aircraft: Compact Position Reporting, or CPR in short. Conceptually, it divides the earth into different zones, and within a zone it only reports the movement inside, therefore dramatically reducing the message size. The real algorithm is way much more complex, which I will not discuss here, but what we need to know is the fact that 35 bits are sufficient to report positions in the worst case, even if we don't use CPR.

This leads us to think: if we work backward, then we can define every single point on the earth as well. That's the way this project works. After gridding the earth into areas, each area will be assigned a number on both latitude direction and longitude direction. The size of the areas will be around 3km by 3km square to ensure both efficiency and locality. This assignment scheme will be loaded into the computer of the aircraft. When the aircraft arrives at a certain location, it will calculate which areas it should broadcast the weather information to, using a pre-specified operation range of the ADS-B system.

Some smart people might have realized something by now and questioned the following three points: 1. How to differentiate the regular information from the weather information? 2. How to ensure that the coverage regions are not overlapped or unserviced? 3. How to ensure that the regular function of ADS-B is not interrupted?

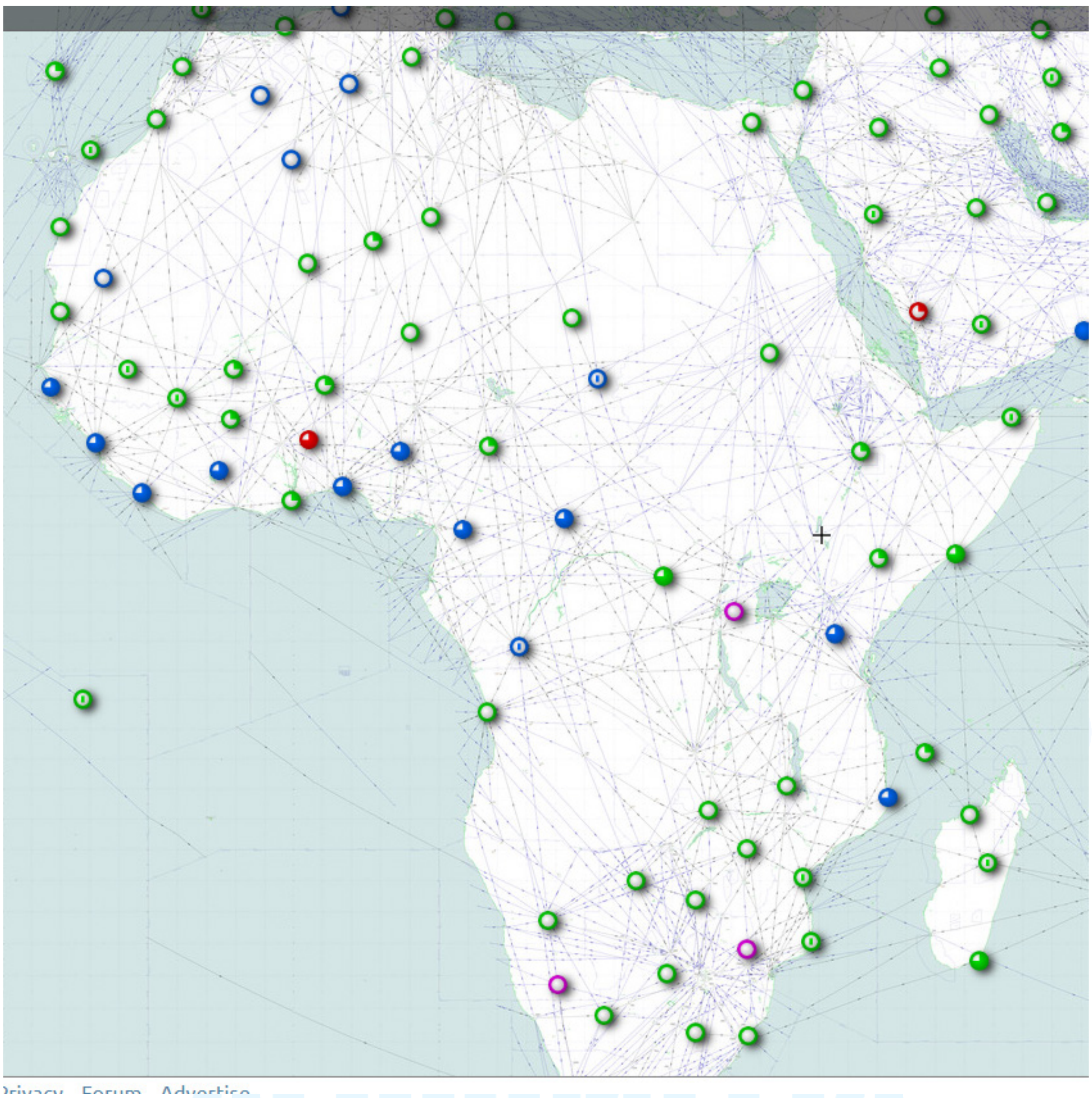
Good questions! For the first one, the answer hides behind the bit 33-37. These five bits serves as "type code" to identify what is actually transmitted. Velocity? Altitude? Position? Currently type 23 (10111) to 27 (11011) are reserved (not used), and current ADS-B receivers don't respond to these type codes. As long as ICAO would agree to assign it, identification is not a problem. Otherwise we can use DF-24 system as well.

For the second question, ICAO stipulated the way the airway and navigation points are made in document 8168. Taken into consideration of backup airport, minimum separation and population density, it is safe to say that most areas will be serviced, if the document requirements were properly observed. In fact, the author can give some examples using the data from Sky Vector to demonstrate this statement:



All these densely distributed lines and arrows are actually airways with the direction indicators. Using the UK as a reference, it is very obvious that the separations between airways are far below the 270km standard.

Africa is not an exception either, which is demonstrated from the screenshot below:



We can see that Africa is also populated with airways and navigation points. Although some areas might feature airway spacings larger than what we expect, it typically serves to avoid hostile encounter, unfavorable terrain, and frequent bad weathers. Most of the human-populated areas will still be properly served.

For the third question, the ADS-B system can typically send six messages per second. It is not very important to inform the ground station every second of the status of the aircraft, as typically there won't be any significant changes during such a short period. If in any worst case of accident (no one really wants but still possible), the investigations will be primarily carried out by interpreting flight data recorder and cockpit voice recorder (FDR and CVR), not really by ADS-B data. The aircraft can transmit regular transponder reply every second, transmit its status information every 3 seconds, and use the time left to transmit weather and market information.

We still have either 21 or 45 bits left free under the assumption that 35 bits were used for position reporting. We probably don't need that many, but let's start from this case. We may assign the following scheme for 21 bits case to compactly report weather or market information. This is intended to be primarily used for aircraft broadcasted information.

```
+---------+---------+-----+--------------+----------------+
|  WS 6  |  WD 3 | T 6  |      CW 5      |  EM/CPR 1 |
                              Or
+--------+------------------+----------------+
|  CT 10  |       CP 10      |  EM/CPR 1 |
```

In the first sub-scheme, *WS* denotes windspeed in kilometer/h (up to 64km/h). *WD* denotes wind direction (NNW, NNE, NWW, NEE, SSW, SSE, SWW, SEE). T denotes temperature (up to 64 degrees centigrade). *CW* denotes the condition weather (32 cases should be more than sufficient for regular regions). Finally, *EM/CPR* bit is used as a flag. When we decide to use CPR to report the position, this bit is used to indicate whether it is an even or odd frame. It not, this is used to flag whether an emergency situation will be approaching. In the second sub-scheme, *CT* denotes the type of crop, *CP* is the price.

We may assign the following scheme for 45 bits case to report weather information in detail. This is primarily intended to be used for information from local sensor stations:

```
+---------+--------+-----+--------------+---------------+---------+--------+
|  WS 7  |  WD 9 | T 6 |      CW 6      |  CPR/EM 1 | ID 11 | NT 5|
                                  Or
+----------+----------------+-----------+----------------+
|  CT 14  |       CP 16      |  MSG 14 | EM/CPR 1 |
```

In the first sub-scheme, all other denotations are the same. *WS* and *CW* were expanded for more accurate localized data processing. Now the wind direction is transmitted in either magnetic or true heading. *ID* here provides a way to assign ID numbers to the sensors deployed for data tracking and maintenance needs. *NT* is a special note that the platform which the sensors should send to the receivers. 00000 will be assigned as "everything ok", while 11111 as "Sensor not working. Please send engineers". All other numbers will be assigned to denote different meanings to like accuracy and credibility of data etc. In the second sub-scheme, the *CT* and *CP* were expanded, and a 14-bit message can be sent as side note.

3.2 System efficiency, security, and encryption

It is expected to transmit the information in an uncoded fashion. As an electrical engineering student who have learned extensively on coding theories, the author would like to point out that the consensus in the field is that when signal to noise ratio, SNR, is below a certain threshold, it is better not to do any coding. Although for the channels used in air to ground (ATG) transmission an extremely low SNR is unlikely, it needs to be investigated if coding scheme will be applicable.

Let's assume it would be possible to do coding for our information. The author would suggest encoding with Reed-Solomon code, Hamming code or Gray code to ensure both decent error correction/protection capability and decoding efficiency, as the computation power is limited for a microcontroller that cost around only 1 USD. Reed-Solomon code is especially recommended, as it is proven very successful on satellite-based ATG communications.

Compression algorithms are not recommended. The LZ family or any family of compression algorithms will not reduce the information size significantly, but will definitely occupy more memory.

System security are ensured primarily via unilateral transmission. The receiver is not allowed to interrogate the transmitter, which can be achieved on a hardware level. Other measures such as air gap system, isolated network and identity validation are another topic which will not be discussed here. Encryption is strongly discouraged, as such a short message might cause security compromises by its nature, not to mention some features of the message is already known, making it even simpler to decipher. But it is still doable. However, the author would recommend using regular RF system for any secured message.

Some people would still worry about “fake messages”. It is actually one of the author’s concern as well. Competing farmers may use malicious device to send some fake messages to disturb or cause trouble to the regular farming of the rival. Fortunately, there are some way out as well. One particularly promising solution is to use the Direction of Arrival (DoA) to generate a key or detect the source of the signal. There are two applicable ways to estimate the DoA: RB-MUSIC (Real Beam-space-Multiple Signal Classification) and ESPRIT (Estimation of Signal Parameters via Rotational Invariance Techniques). Although the author has investigated them to a certain extent, the author would not prefer to claim himself as any sort of expert, and both algorithms are quite computation-intensive. Mentioning them serves just to inform the reader.

3.3 Transmission and communication scheme

In the aircraft, the only necessary step is to do a software update. On the ground, the transmission scheme can be based on any of the following solutions: pure regular Bluetooth, pure WIFI, LoRa+ BLE, BLE+WIFI, pure BLE, pure LoRa. The last three solutions are recommended, with the pure BLE and pure LoRa being the most recommended options. Actually, for any of WIFI, Bluetooth and LoRa to work properly over long distances, a line of sight (LOF) is typically necessary. Although BLE doesn’t perform extremely well, the performance is still decent for 112 bits’ message. The same thing is for the LoRa. Although there is a trade-off of data rate, for 112 bits things are still fine. If in any case larger message would need to be transmitted, we may use BLE to establish a pairing and then use the WIFI to transmit the data.

The “Mesh” and “Decentralized” come from the fact that using newest Bluetooth 5.1, devices within a network form a mesh and greatly enhance the network stability and accessibility. As long as one user in the network receives the message, all others can enjoy it as well. No “central device” is necessary anymore. Everyone is a node.

Meanwhile “Enhancable” means that embedded systems can be enhanced (upgraded) with extra modules or new codes for more functionality. For example, using baseband and modem module, the system can join the mobile network in a “plug and play” fashion. With built-in WIFI chip it can be remotely updated as well. Another example is that if battery life of phone is not main concern, it is also possible to enable the communication of the device with the phone, and show the data received on the screen, and the only thing necessary is to add a jump wire. Some further possible updates will be given in the following chapters.

3.4 Power supply, battery life, and maintenance concern

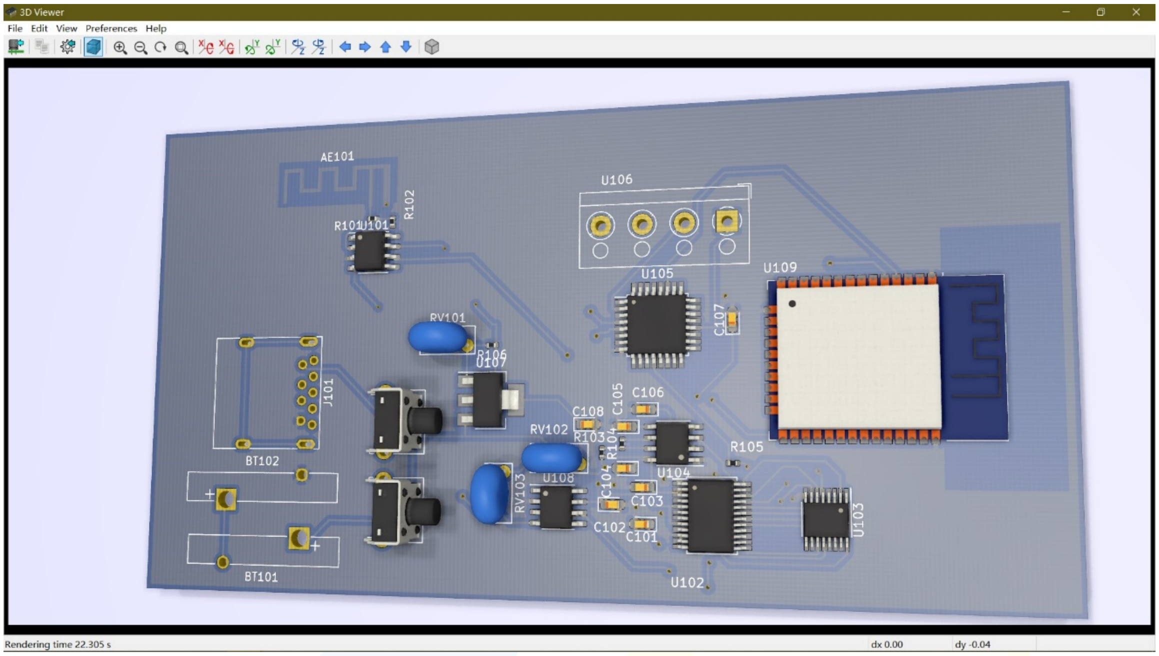
The device is designed with capability to work on either phone battery using the 5V supply of USB port, or on button battery. By default, it chooses the 5V supply. When phone battery depletes, it can work on backup mode with two CR2025 button batteries, as this particular battery is widely available.

The microcontroller will be programmed to go into low power idle mode after some inactive time to save battery. By specification the two batteries can last at least 40 hours before replacement, assuming the device is drawing maximum power. Some devices with LoRa and specially designed low energy microcontrollers even claimed a battery life of 5 years to 10 years with AA batteries. Therefore, the author believes that battery life should not be any problem.

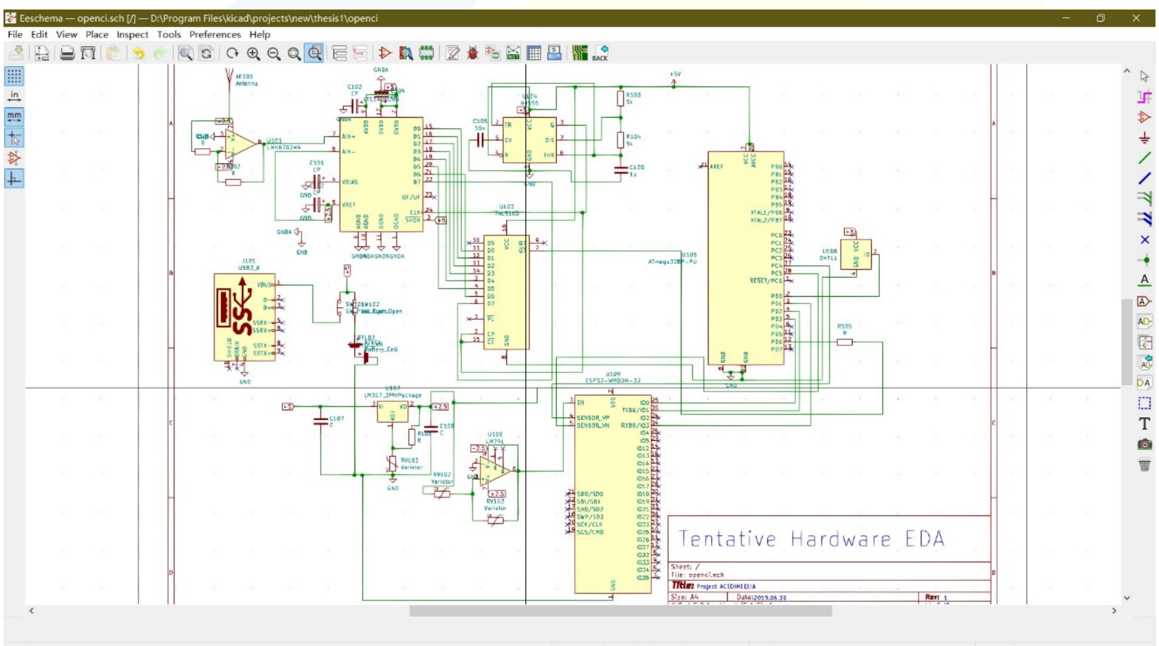
Most of the extra sensors on the sensor platform will be built as separate components so that they can be easily swapped. On the farmers' side, the receiver is built into an external casing made by ABS plastic. During daily operation, the device can work as a protection case for the phone as well. When the board is malfunctioning, it can be easily swapped out also.

4. Sample electrical design

Although the author will demonstrate the system using commercially available ESP32 development board to avoid waiting several weeks for a custom PCB, the author still performed an Electronic Design Automation (EDA) of the intended development board. The real product will be built with most of the components being SMD devices. The EDA file and circuit diagram will also be published on my GitHub.



Sample render of the board



Sample Circuit Diagram

U105 is an ATMEGA328, with U102 and 103 being Analog-Digital converter and shift register. U101 and U108 are left for operational amplifiers. U107 is a LM317 regulator, and U104 is a 555 timer. An embedded SMD antenna was chosen. U106 is a four-pin socket for the sensors to be plugged in. The largest U109 is an ESP32 combined chip with WIFI/Bluetooth/BLE and its own antenna. BT101 and BT102 are two battery holders for CR2025 in vertical, and J101 is a standard USB type-C port.

To get a clear understanding of how small the design actually is, the author would like to mention the fact that even with such a low space utilization and those bulky button switches and variable resistors (RV labels), it still occupies only 9cm x 6cm space. After the development is finished, basically all components can be replaced by SMD, and the area can be reduced to a quarter of what this design occupies.

5. Technical advantages

During the design phase, the author has scrutinized all other "ideas" posted on the website. Comparing to other solutions envisioned, the most significant advantage is that this solution is really practical, cheap and easy to realize, meanwhile fulfilling almost all requirements that "Solutions could take the form of" have suggested.

5.1 Advantage over SMS/USSD

First of all, for SMS, USSD and website-based solutions, the prerequisite is that mobile network must be available, and the ISPs are willing to cooperate. For many cases this is not true. As the author mentioned in the description, even in countries as developed as Germany, there are cases where no network is available at all, not to mention mobile data. Besides, USSD codes are not so easy to use user-wise, as you need to remember some weird codes to send to your ISP every time, but ISP will have some trouble handling a large number of USSD requests also.

Some people also mentioned that USSD bypassed the requirement to charge the users. But actually, somebody must bear the cost of electricity and transmission band (which is auctioned for every generation of mobile system). For private business ISPs, they will typically not be willing to provide such support. For Africa in specific, the infrastructure is not as advanced as other countries. If the message failed to deliver to a certain region, it will cause fairness issues and possibly cause social unrest. SMS has its limit as well due to established international protocols.

But for project AECDIMEEIA to work, the only requirement is that either in the 270km around you a friendly aircraft passes by, or your local weather station works and there is someone around you in 1km (for BLE) or 10km (for LoRa), which is highly likely for small rural communities that the contest aimed to support. Mobile network coverage, communication band license, or additional infrastructure is not required at all. Also, ADS-B is a very new scheme. As long as you are not unreasonably far away, you can still get the data, and for ADS-B based information transmission, the protocol is not yet fixed. There is still some room for discussion and revision.

Besides, phones are still much more expensive than an embedded system. The detailed bill of materials and price estimation will be provided in the business report, but from calculation 4.91USD are more than sufficient for mass production. The author doesn't think 5 dollars would be sufficient to buy a phone, even if it is secondhand.

5.2 Advantage over other IoT and robotics designs

What this design is different from the other IoT, Internet of Things, ideas from our "competitors" is that although they claimed themselves as building an IoT device, it is by nature still an "off the shelf" development board which uses very simple implementations of pre-built functions, which costs about 12USD at least and some even claims 50USD.

But meanwhile it is very unreliable, as it uses multi-layer board which is vulnerable against moisture and dust. For farmers, spending 12 dollars for something that broke every month is not attractive at all. It is the same thing for robotics. They are vulnerable and expensive, and in fact is an "overkill" for farmers in most cases.

In project AECDMEEIA, the author, with much experience in hardware design, intentionally uses special board processing (edge trimming, impedance matching, conformal coating and some more) and routing techniques during EDA to make the device very robust and fail-safe. In fact, even if some water is spilled on it, the farmers can simply drain the water, and the device will still work properly.

In other words, although we also used an "off-the-shelf" board, it is not because we have to use it. Instead, we did the serious design and really designed a "workhorse", rather than using the example codes offered by the manufacturer to make some fancy toys.

5.3 Side benefit

A side benefit is to promote the development of aviation. There has long been the claim from farmers that planes bring nothing to them except noise and loss of sleep. But now planes bring information of the market and emergency to them. It is expected that the disagreement for planning airway will be less intense after this system is applied. It will lead to easier and more efficient airway planning and airspace utilization, reduce fuel burn, and build a healthy and positive cycle for civil aviation thereafter.

5.4 Core advantage

Most important of all, being an IoT system, project AECDIMEEIA is by nature "future-proof". All current progress and technologies in this field can be applied to the design directly. For example, ABB has implemented community-oriented central management system for lighting and heating in a tourist village. It can be directly implemented to our design as well. Siemens has a "Industry 4.0" enabled factory. Their sensor management network can also be transplanted to be used here. These are just some simple envisions and our good friend from the industry might not be so willing to support. But still, it is better than nothing.

6. Function demonstration

The system is designed with Arduino IDE and demonstrated on an ESP32 development board, as it is quite popular and has multiple functionalities. Most importantly, with this board the fruitless waiting time for a PCB can be omitted.

Also, as Bluetooth operates on 2.4GHz, to avoid jamming with omnipresent WIFI signals in China, the author will demonstrate the system via LoRa. To use BLE, please simply change the initialization command, send and receive commands and parse command in the source from LoRa.xxxxx to BLE.xxxxx.

In the test, the author will primarily demonstrate the followings:

1. How the sensor collects data and transmit it to the platform.

2. How the platform communicates with others.

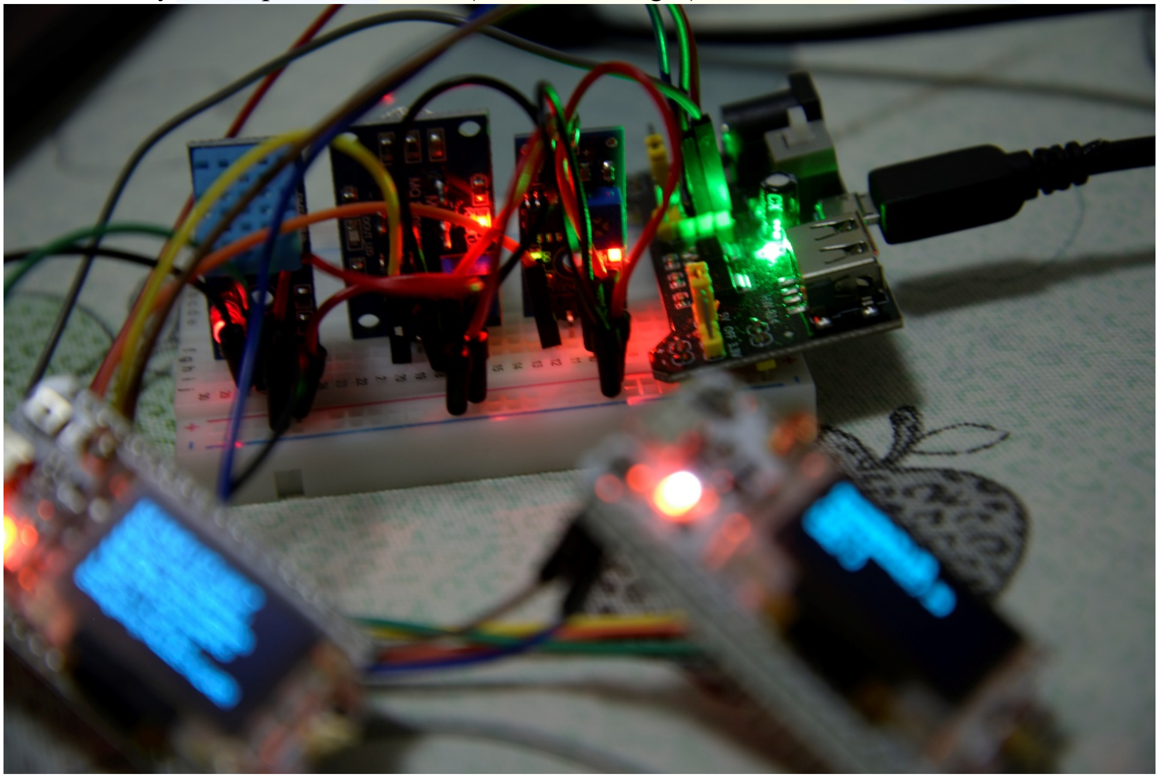
3. How the information is deciphered and presented for different types of data sources.

4. How the information from unacceptable data sources are rejected.

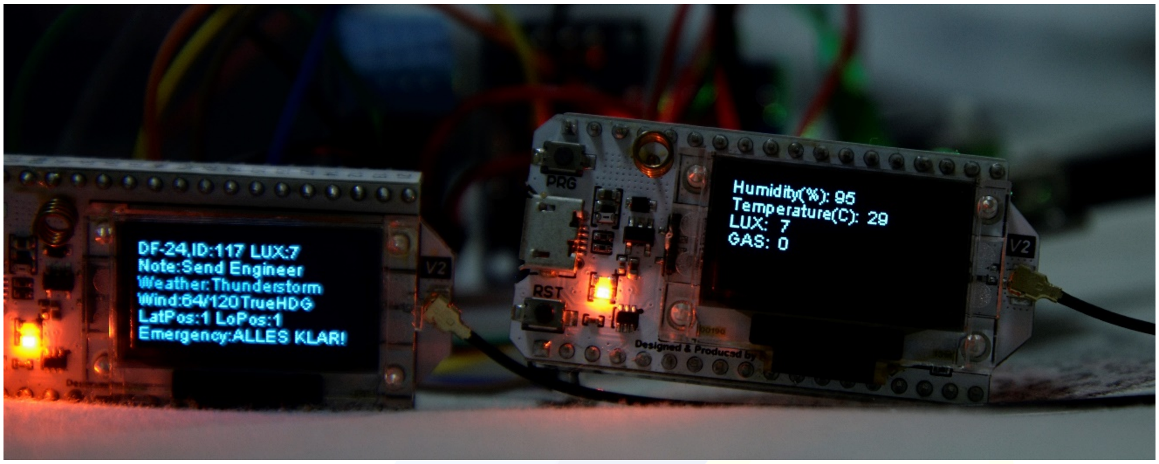
5. The performance of LoRa system.

The author should admit here that automatic power management and CRC (parity check) will not be demonstrated. The reason behind it is that this board is forbidden by the manufacturer to be powered via battery for some reasons, and it takes several seconds for the device to recover from low power mode. Besides, LoRa has a CRC function, and it was forced-enabled by the manufacturer for this board. For operation on custom-designed boards these are not problems, but for demonstration whose time is limited to only two minutes, the author prefers to run everything on normal mode.

1. The sensor station collects the data from the sensors via pull reading. The device initializes LoRa function, which works in the same way as regular WIFI, and now it is able to communicate with other devices. The LoRa library is slightly modified in terms of parameters for better performance. Here the author used luminosity sensor, gas sensor and humidity & temperature sensor (from left to right).



After the data was obtained, it was printed on the screen. Below, the screen on the right demonstrates this scenario.



3. We use a DF-18 system for “aircraft-based data”. The string is pre-defined with the following case: 32km/h wind speed from SSW, 32°C, thunder storm, emergency situation alert, intended for area (1,1). In real application, these data will be collected from sensors.

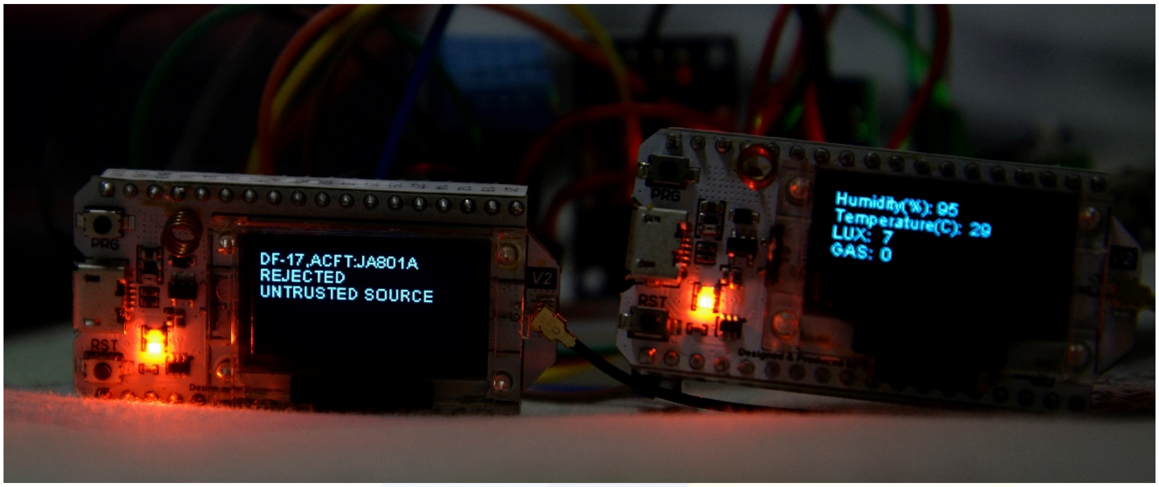
We use a DF-24 system for “data from local sensor stations”, which is the data we collected with our sensors for this demonstration. The configuration is as follows: sensor No.117, luminosity data collected from the sensor, 64km/h wind from 120° true heading, thunderstorm, no emergency, intended for area (1,1).

We concatenate the data into a string and apply the aforementioned ADS-B format to it. The device transmits the data in packets, while on the receiver side, the receiver tries to receive the packet and parse it to retrieve the data. If the data can be correctly interpreted, then it is displayed. (please see codes for more details of this part)

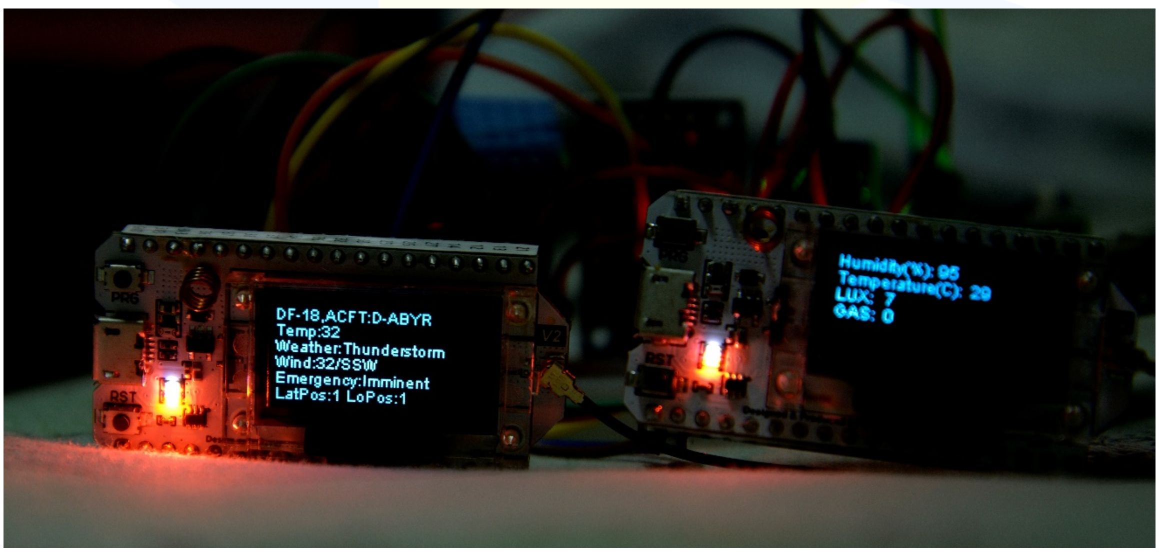
Please note that the either of the two devices can work as transmitter or receiver. Because with some efforts, it can even work in receiver and transmitter duplex mode. But as the author only purchased two boards with limited budget, it doesn’t make too much sense to configure them as TX-RX Duplex.

4. When interpreting the data, the device first examines whether the data copes with the legitimate DF codes. If so and DF is not 24, the device later examines the ICAO address contained in the data. For DF-24 system, the device examines if the ID number is legitimate. If legitimacy is secured, the data is printed on the screen. Below is an

illegitimate message, as we assumed that we are not allowed to receive the data from Japanese aircraft. So, this message from ANA's JA801A is discarded.

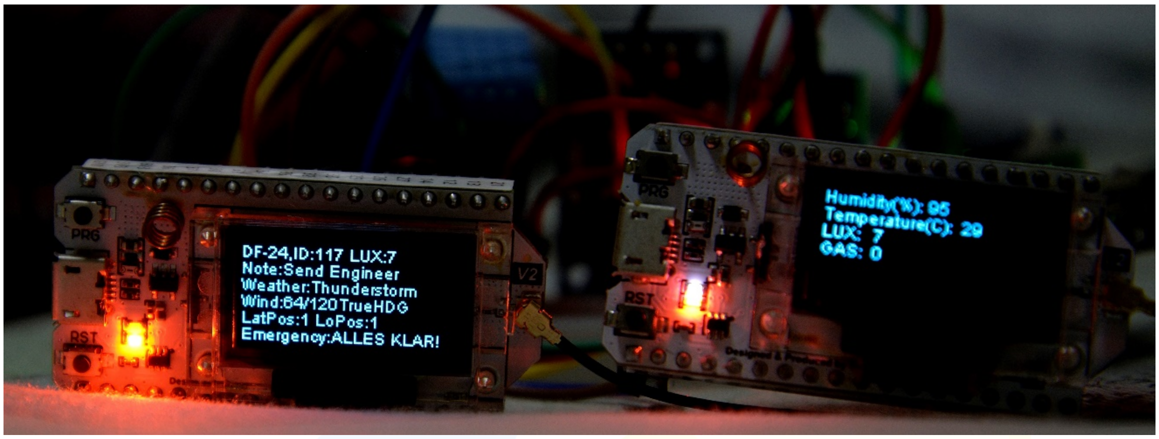


Now we received another message from D-ABYR of Lufthansa, which is allowed. Therefore, we decided to interpret the data. The interpreted data agrees with what is sent by the transmitter. Also, please take a more careful look at the LEDs on the two boards. You might notice that there are actually two LEDs blinking. The white one on the top is used to indicate that the packet is sent on the transmitter side, and it indicates that the packet is parsed and read on the receiver side.

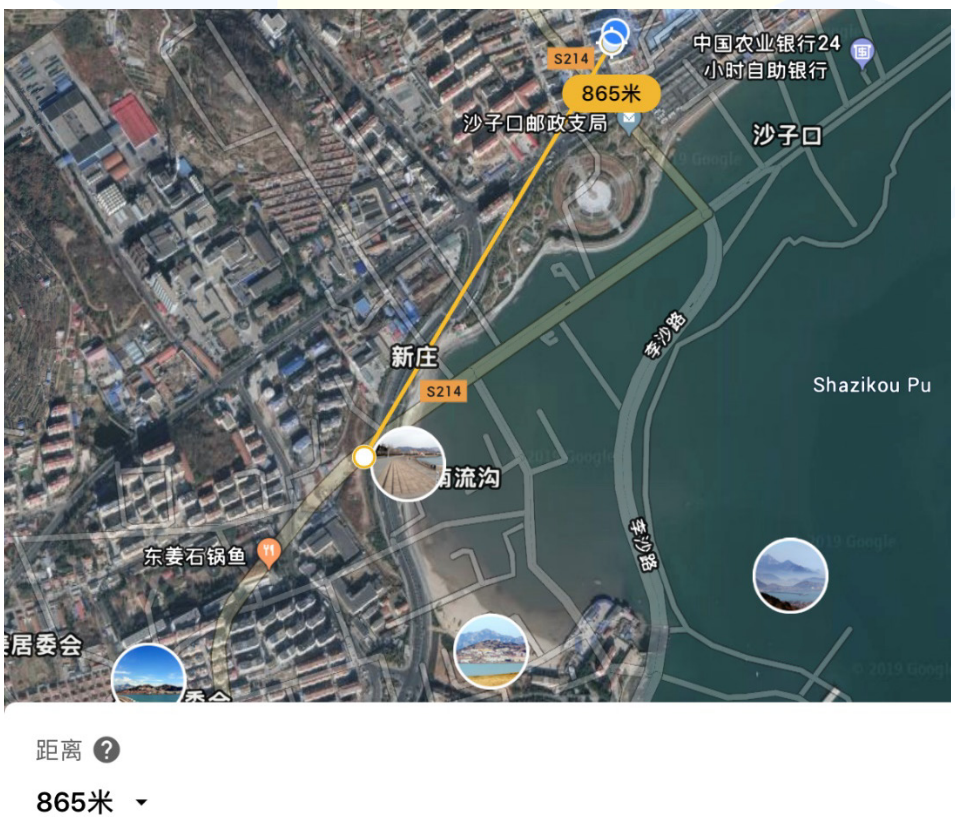


You can see that as information is transmitted, an emergency notice is also transmitted, with the location where the message intends to service also indicated. If we add a speaker, an aural warning can also be issued. These features are very important for intended use cases (see business report for more details).

Now we receive a DF-24 message. Still, we check if the ID is legitimate, which is the case. Therefore, we decipher the message. For DF-24, you can see that beside the emergency message, a side note is sent as intended. The farmers who received the message can inform the technician in time for maintenance work when necessary and reduce human labor cost. Now as the screen said, Alles klar!



5. The author proved a working range of 865 meters, from (36°06’55’’N, 120°32’21’’E) to (36°06’32’’N, 120°32’07’’E) as indicated by external GPS. It might be able to work over even longer distance, but due to terrain, a LOF larger than that cannot be achieved in the region around. Below is a screen shot of Google earth that indicated the path (LOF).



7. Further extension

The functionality of the project is not limited to what's demonstrated in this report. In fact, although it was not explicitly mentioned in the codes, the device initializes the SPI function by default. It also has onboard USB interface controller. Therefore, the functionality can be customized and data can be presented on the smartphone via USB or WIFI/BLE if required. Additionally, if we really want to challenge other ideas from competitors, well, without any budget we can cooperate with airport to change ATIS message which outperforms solutions which uses airport weather stations. With a 6USD module we can also send SMS/USSD message. With some more budget, we can also build a robot. It's really simple for electrical engineers, but this is not what OpenCI really intends to achieve, so the author decided not to work on this direction to challenge others.

Though the demonstrated functionalities fall primarily into "crowdsourced nowcast", "information pipeline" and "packaging information", it is also doable to integrate sensors for crowdsource weather monitoring, with the data transmitted in the aforementioned scheme. The luminosity information transmitted in the DF-24 scheme is an example. No hardware modification is necessary. The exact content of the messages can also be customized. In fact, we only used 28 bits for location transmission, therefore the extra free bits can be used to provide 2^n cases for different messages and functionalities, such as the type of emergency, intensity, and suggestions from the authorities.

8. Conclusion

To summarize, this project managed to find a "sweet-spot" between affordability and performance, with the novel approach of utilizing IoT and aircraft-based modern communication system to deliver weather, market, and emergency information to people with reduced information accessibility. A hardware EDA is provided which offers intended functionality at a cost of 4.91USD and can be further reduced. A tentative but detailed technical specification is properly developed and analyzed, with all common concerns addressed. A technical demonstration based on ESP development board is provided. This solution is by nature an IoT system, which enjoys all advancements in this field. The design is technically advanced over USSD/SMS solutions, and supersedes other development-board based solutions in robustness and price. Meanwhile, its most unique advantage is that it can influence the community and further the country, which competing solutions are unlikely to achieve.

Appendix: Something the author would like to say

First of all, on behalf of the entire team, the author, Zihao LIU myself, would like to again deliver our most sincere appreciation to all the reviewers and staff who took the efforts to evaluate this project and provided with administrative support. I hope that you had a nice time reading this report, or at least as I said, “enjoying the nice Weissbier und Schweinshaxe” 😆.

I know reading this report is probably like chewing a tire (Reifen if you prefer Deutsch) for people who don’t like EE, and I used quite a lot of “directive statements” and omitted some trivial details (which I took for granted due to my EE background) without actually expanding or give proof. For example, I didn’t mention that ADS-B message needs a “11111” initializer sequence spaced 8us in between.

But I, as one of the EE engineers out there, am trained to handle these problems and get paid for it. It is totally fine to avoid those headaches and let the professionals do it. So, for those who made it here, congratulations anyway. Our team believes that this design, which the author seriously and painstakingly designed, tested, and documented, undeniably stands out among competitors. We would definitely appreciate any favorable consideration.

Finally, all documents referred to have been explicitly mentioned throughout this report. All software used have also been mentioned. The documents related to this project, which include but is not limited to, business report and technical report, are the intellectual property of the author and Mr. Hanyu LIU. The logo is the design of Mr. Yuhai CAO. Unless otherwise stated, these documents, hardcopies, photos and illustrations are licensed under CC-BY-4.0. The source codes are licensed under AGPL3.0. Please contact the author before any commercial use.

Finally, and most importantly, have a nice day.

Auf Wiedersehen!