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Are Wireless Sensors Feasible for Aircraft?

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Abstract: Wireless communications is a preferred way of data transmission in many aerospace applications. Replacing some aircraft sensor wiring with wireless communications is a highly desirable but challenging transformation. The related sensors are referred to as aerospace wireless sensors (AWSs). This replacement can lower the weight of aircraft wiring, improve the overall safety of aircraft, simplify the design of aircraft structures, and lower the sensor installation and maintenance cost. The major concern for using AWSs is the potential negative effects on overall reliability and safety of aircraft. In this paper, the feasibility of using AWSs is discussed. In particular, the appropriate wireless communication schemes are studied in terms of immunity to jamming signals, interference to other on-board wireless systems, simultaneous data transmission from multiple AWSs, and low detectability to unintended parties. We conclude that the code-division multiple-access (CDMA) is a suitable scheme for this application.

1. Introduction

Electrical wiring on board aircraft has raised serious weight and safety concerns in the aerospace industry. Wires are antennas. Wires that carry signals, particularly high speed data, can radiate some of the energy of those signals. This can cause interference to radio-based systems on board the aircraft, or, in the case of military aircraft, create a "signature" that can be detected by enemy receivers.

Antennas can also receive energy from electromagnetic fields. Modern aircraft have a number of on-board transmitters that can interfere with flight-critical data carried by wires. There are also high intensity radiated energy sources external to the aircraft. These would include flying near radar transmitters, high powered broadcast transmitters. High energy pulses are also experienced by aircraft such as a direct lightning strike and electromagnetic pulse from weapons detonation.

Even though well-designed transmission lines reduce signal egress and ingress, the price to pay is heavy, expensive wires. As reported in recent conferences on aircraft and aviation technology, some Blackhawk helicopters carry more than 900 kilograms of wire connecting all the computers and sensors, which significantly affects the payload capacity of the vehicle. Also, electrical wiring problems in the U.S. Navy cause an average of two in-flight fires every month as well as more than 1077 mission aborts and over a hundred thousand lost mission hours per year. Each year, the U.S. Navy spends one to two million man-hours finding and fixing wiring problems. In addition, running wiring in the structure of the aircraft and maintenance of the wiring are both time-consuming and costly.

Although wireless sensors deliberately use antennas, the frequency and bandwidth are controlled to insure electromagnetic compatibility. Undoubtedly, replacing some of the aerospace sensor wiring by wireless communications offers significant operational and cost benefits. For example, for hardware that is periodically added to and removed from a given airframe, flexible wireless links provide an efficient solution. Also, wireless communications is the only choice for many applications where wired communications is not practically possible. Yet, current aviation certification requirements do not allow wireless communications to be used to connect aircraft sensors. Regulatory bodies and the aerospace industry are starting to consider this transformation.

2. Feasibility and Technical Issues to be Addressed

It is not appropriate for aircraft sensors in all applications to be converted to wireless sensors. For instance, AWSs are not suitable in following scenarios:

1. Sensors that generate large amount of data, in which case going wireless can result in excessive demand for radio spectrum, a scarce resource.
2. Sensors that have to be placed in areas of poor signal propagation.
3. Sensors used in applications that demand extremely high reliability. In this scenario, strong jamming signals can be a serious problem for AWSs. Wireless links are required to have certain level of immunity to moderate jamming signals, but they are always vulnerable to strong ones.

To provide feasible wireless links, several issues concerning AWSs need to be addressed properly, including: immunity to jamming signals (including unintentional interference), interference to other on-board wireless systems, interference among multiple wireless links between different AWSs, and detectability to unintended parties. In this paper, we address these issues by carefully considering the wireless communication schemes for AWSs. We will show that the direct-sequence spread-spectrum (DSSS) technique is an appropriate scheme for AWSs due to its simplicity of system implementation and convenience in realizing multiple access (MA), a scheme known as code-division multiple access (CDMA).

3. Characteristics of AWS Communications

Due to the structure of aircraft, multiple access points (APs) may be needed to provide the wireless links between AWSs and an on-board data processing center (DPC), as illustrated in Figure 1. Note that the connection between the DPC and APs is wired. The channel of the wireless link between an AP and an AWS has the following characteristics:

1. In general, AWS transmitters are in the vicinity of receivers.
2. Signal propagation between AWSs is over multi-path. This may result in time delay spread.
3. In the case of narrow-band AWS signals, the wireless channel can be modeled as a flat fading channel, i.e., the channel's fading parameter to the AWS signal is constant over the signal bandwidth.

4. The channel is almost stationary, i.e., the channel's fading parameter can be considered a constant over the duration of AWS communications. Although there may be moving objects in the environment, such as crew members or moving mechanical parts, the movement is very slow considering the duration of AWS communications and thus can be ignored.

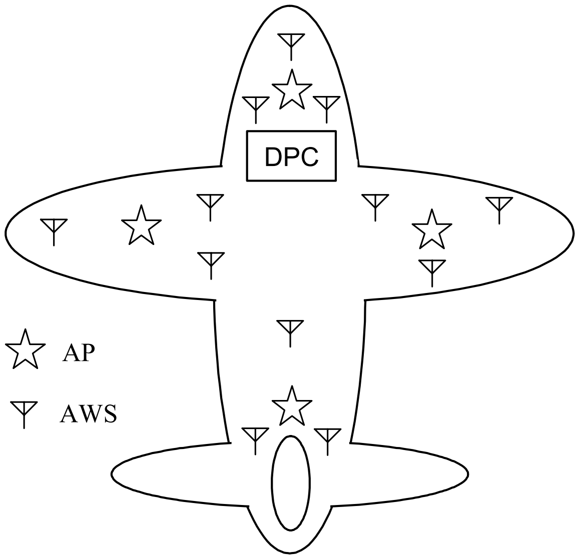

Figure 1. Locations of DPC, APs, and AWSs

An AP and the AWSs it serves communicate in two ways: an uplink from the AWSs to the AP and a downlink the opposite way. The characteristics of AWSs links are as follows:

1. The uplink and downlink are asymmetrical. The AWSs are mainly used to collect and send data to the DPC, so the uplink data load is much heavier than the downlink.
2. The receiver and transmitter of an AWS should be as simple as possible. Signal processing can be performed at the AP side to guarantee the pre-specified bit-error-rate.

3. The amount of data generated at each AWS is not large, and the transmission data rate is typically in the order of 1 kilobits per second (kb/s).
4. The transmission is bursty in nature. Therefore, time interleaving is not needed before channel error-correction coding.

4. Spectrum and Communication Schemes for AWS

Concerning the choice of the spectrum for AWS communications, the major requirement is to avoid possible radio frequency interference (RFI) with existing navigation and communication instruments. We believe an ISM (industrial, scientific and medical) band, such as the 5 GHz ISM band, can be used before dedicated spectrum is allocated. Currently, this band is mainly used by IEEE 802.11a-compatible WLAN (wireless local area networks) devices, and the entire bandwidth is divided into multiple channels of 20 MHz channel spacing. IEEE 802.11a-compatible WLAN devices transmit in an 18 MHz bandwidth mask. Hence, the available bandwidth between two channels is $20 - 18 = 2$ MHz. If we use a channel with 1 MHz bandwidth in the middle, the AWSs and WLAN devices will not affect each other even if they work simultaneously over the same geographical area. Therefore, this band is available to AWSs as long as the transmission power is limited to a proper level. In addition, this band supports simple antenna and is protected by international agreement.

Our choice of communication scheme for AWS is DSSS. As an illustration, a schematic of an uplink transmitter and receiver using DSSS is shown in Figure 2.

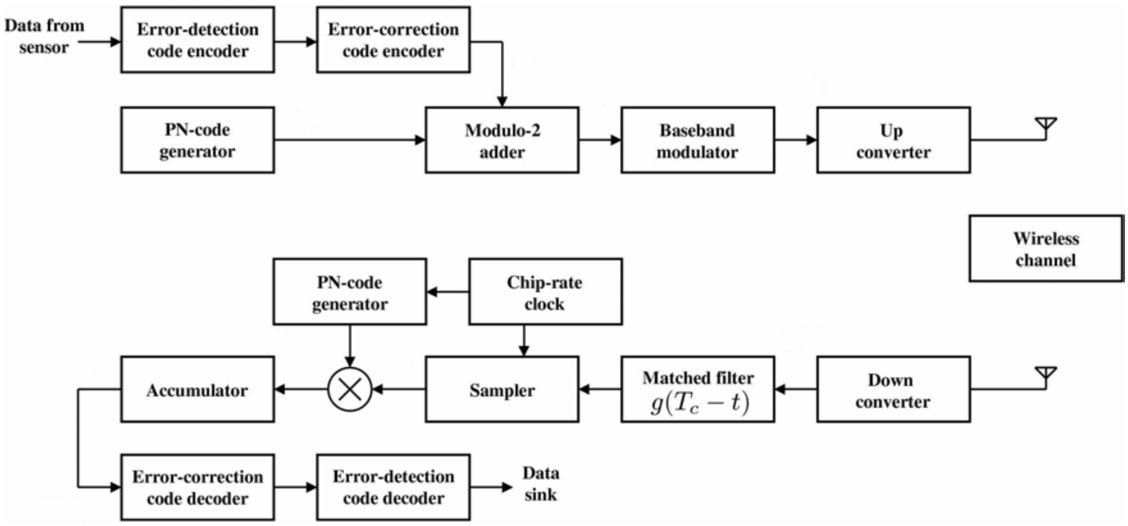

Figure 2. Schematic of Uplink Transmitter and Receiver

Now we demonstrate that DSSS is a promising communication scheme that meets the requirements for AWS communications:

1. Immunity to jamming signals: Since directional antennas or beamforming are not feasible for AWSs and increasing the signal level is not allowed, we can only battle jamming signals through intelligent use of bandwidth. To battle narrowband jamming signals, we can adopt either the DSSS scheme or the FHSS (frequency-hopping spread-spectrum) scheme, or a combination of the two. DSSS achieves the suppression by the processing gain resulted from spectrum spreading, while FHSS avoids the jamming signals via frequency relocation. To battle broadband jamming signals, we can also use these two schemes. While DSSS still uses processing gain, FHSS uses higher average power in the narrow band it occupies. Due to the existence of jamming in every frequency hopped, the performance of FHSS degrades compared to the case of narrowband jamming. While both DSSS and FHSS are able to battle moderate jamming signals effectively, we prefer the DSSS scheme due to the following reasons:

a) DSSS is easier to implement than FHSS;

b) Signal processing for receiving DSSS signals is easier to implement than for receiving FHSS signals at the APs (and at the DPC);

c) Multiple-access with DSSS, namely CDMA, is easier to achieve than with FHSS.

2. Interference to existing wireless systems: There will be no noticeable interference to existing wireless systems on-board aircraft if the DSSS scheme is used in the frequency band discussed above. The reasons are:

   a) The EMC (electromagnetic compatibility) requirements of existing wireless systems dictate that these systems are immune to moderate interferences from ISM bands;

   b) Because DSSS signals occupy a broad frequency band, the power spectral density is very low. At an appropriate distance, the average power of DSSS signals will be lower than the thermal noise to most existing wireless systems, which is much lower than the moderate ISM band interferences mentioned above.

   c) Even if IEEE 802.11a-compatible WLAN devices are allowed in aircraft in the future, the interference to these devices caused by AWS signals is still negligible due to the low power spectral density.

3. Interference between wireless communications for different AWSs:

   a) For downlink CDMA transmission, orthogonal codes can be used to avoid the interference between different users. Hence the interference between multiple AWSs will not occur.

b) For uplink CDMA transmission, the interference between multiple sensors can be limited to a tolerable level by controlling the number of simultaneous users and controlling the power of each transmitting user. This is much like the conventional CDMA cellular communications. The transmission is bursty in nature; hence a large number of AWSs can be accommodated by an AP if the transmission slots of the sensors are evenly distributed.

4. Low detectability to unintended parties: The AWS communications should have very low detectability to unintended parties. We consider the detectability in two aspects:

a) The detectability of the existence of communication signals: this type of detection is difficult because the emission levels are very low --- below the noise level.

b) The detectability of the data symbols contained in the communication signals: this type of detection is even more difficult due to the low level of emission. Besides, detection of data symbols depends on the knowledge of channel parameters, which are difficult to be estimated by unintended parties due to the lack of knowledge of the training sequence. In addition, without the knowledge of the channel error detection/correction code, detection becomes even more unlikely.

5. Conclusions

In this paper, we addressed the technical feasibility of using wireless communications to replace wires for some aircraft sensors. We illustrated that, the AWS communication systems employing CDMA can appropriately handle the following issues: (a) jamming signals (including unintentional interferences); (b) interference to other on-board wireless systems; (c) interference between multiple AWS links; and (d) detectability by unintended parties. Hopefully, the aviation certification requirements will accommodate this important transformation in the near future.

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