Wireless Communication in Missiles: Challenges

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1. INTRODUCTION

The secured and high speed data wireless data networks is the order of the day in missile communication. Future systems may demand a data communication up to 10 Mbps or more. Communicating at high transmission rates over the harsh wireless environment, however, creates many difficult and challenging problems. The requirement of high RF bandwidth and implementation difficulties discourages the development of such system.

In this paper, the challenges of RF communication in missile and the modern wireless communication trends are presented. The secured spread-spectrum techniques such as Direct Sequence Spread Spectrum (DS-SS) and Frequency Hopping Spread Spectrum (FH-SS) and their characteristics are explained. Their advantage and jamming performance is briefly discussed. The modern high data rate multi-carrier techniques such as Orthogonal Frequency Division Multiplexing (OFDM) technique and its limitations are presented. The OFDM is a non-secure system and its operation is affected by presence of Doppler because of high dynamics of missiles.

For the missile applications, a multi-carrier CDMA (MC-CDMA) technique which combines the security features of spread-spectrum and high speed feature of OFDM is briefly presented. The Doppler impact is less in MC-CDMA because of less number of sub-carriers. A MC-CDMA with 4 orthogonal carriers and 64 Walsh codes is adequate for missile applications. A new multi-code Direct Sequence Spread Spectrum is described which assigns a large number of orthogonal DS-SS codes to an individual user in order to achieve high data rates. Further, the concept of point-to-point RF data link, non-line-of-sight communication and anad-hoc network is presented.

2. WIRELESS COMMUNICATION IN MISSELS: CHALLENGES

One of major critical aspect of missile development process is design of wireless communication system to suit the specific mission requirements. The following design constraints must be addressed and an optimum communication scheme should be selected during the design of a communication system.

2.1 High Missile Dynamics

The high velocity and accelerations with associated vibrations, roll and other mechanical disturbances is a major concern to the wireless data communication and the equipment. The high velocity leads to high doppler frequency which create problems in tracking receivers.

2.2 Communication Resource Utilization

The communication system should be efficient from the point of view of transmit power and signal bandwidth. The transmit power is mainly decided by the range of operation, signal bandwidth and signal to noise ratio of the proposed modulation method. Again, the power supply requirements largely depends upon the time of flight and transmit power. All the resource requirements are interlinked and are of conflicting nature.

2.3 Reliable Communication

The communication service should be reliable in terms of availability and quality. To ensure availability, hot redundant standby system are necessary. Quality is assured by using channel encoding schemes which further increase the signal bandwidth.

2.4 Diversity

It is another efficient way to ensure communication availability. The space and frequency diversity methods are desirable.

2.5 Worst Aspect Angle Geometry

During the flight of missile there are situations when the aspect angle geometry between transmit antenna and receive antenna is worst which leads to communication loss. The aspect angle geometry is improved by increasing antenna beam-widths and space diversity.

2.6 Plume Attenuation

Mostly communication takes place through the missile plume. The large amount of attenuation occurs because of plume which need to overcome for continuity in communication.
2.7 ECCM

Mostly the missiles are operative in hostile area and therefore, adequate ECCM measures are required in communication system design. During warfare situations the systems should reliably operate in heavy signal interference conditions. It can be a co-channel interference or a jammer in hostile area. The design should take into account these requirements.

2.8 Small Component Size and Light Weight

The design of communication system in conflicting requirements always demand space. The use of space diversity and hot standby redundancy is at the cost of extra space and weight. Long range missiles need high transmit power which leads to large heat generation that needs to be properly dissipated.

3. WHY DIGITAL DATA COMMUNICATION IN MISSILES?

The digital communication system is preferred in missiles because of its high reliability, better performance and flexibility. Following are the main characteristics of digital communication system:

- High noise immunity in fading conditions.
- Multiplexing for multiple users using FDMA, TDMA, CDMA, etc.
- Information security with the help of data encryption.
- Integration of different form of information such as, video and data.
- Integrated networks within communication system can be implemented to increase the availability and reliability.

In digital communication system the information signals are processed at very high speed. The availability of high speed ADCs and high performance VLSI technology makes it possible to process the signals at extremely high speed. Lots of sophisticated DSP algorithms are available today to handle the signals efficiently.

4. CONVENTIONAL COMMUNICATION SYSTEM

The block diagram of conventional one way communication system is given in Fig. 1. It consists of a transmitter and a receiver.

![Figure 1. Basic block diagram of wireless communication system.](image)

The transmitter consists of a modulator, a power amplifier and a transmit antenna. The receiver consists of a receive antenna and a demodulator. The data is modulated by a carrier in modulator and the modulated signal is power amplified and radiated by the transmit antenna. In the receiver, the receive antenna receives the signal and is fed to a demodulator. The demodulator multiplies the received signal by a locally generated carrier to get the original transmitted data. The carrier in the receiver should be the replica of transmitter carrier as far as phase and frequency is concerned. Such a carrier is locally generated in receiver before demodulation.

In wireless communication system the transmitted signal is mainly attenuated and distorted in the channel in which it travels which results into erroneous demodulated data. The channel encoding techniques help in recovering the error free data. The redundancy information is added to data in transmitter in channel encoder block. In the receiver, the channel decoder uses the redundancy in correcting the erroneous data.

5. MODERN TRENDS IN DIGITAL COMMUNICATION

Signal security and high data rate is a order of the day in military communication. The signal security at the physical layer is provided by spread-spectrum communication and high data rate communication is implemented by multichannel system. Modern military system uses these techniques to improve the communication performance in hostile areas.

5.1 Spread Spectrum Communication

Spread spectrum is a means of information transmission in which the transmitted signal is spread over a wide frequency band, much wider than the minimum necessary to send the information. The band spreading of data is accomplished by mixing with a wideband pseudo-random sequence (PN sequence) which is independent of the data. The spread spectrum air interface offer following advantages over conventional communication system.

- Low probability of detection (LPD)
- Low probability of intercept (LPI) > 15 dB
- Better Anti-jamming (A/J) margin > 15 dB
- Multi-path mitigation (Delay > ½ chip width)
- Multiple Access using Code Division Multiple Access (CDMA) and
- Selective availability

The types of spread-spectrum techniques are as follows:

- Direct Sequence Spread Spectrum (DS-SS)
- Frequency Hopping Spread Spectrum (FH-SS)
- Time Hopping Spread Spectrum (TH-SS)
- Hybrid forms

The hybrid form is a combination of above systems which gives a more complex air interface and offer efficient signal security features than an individual spread-spectrum technique.

5.1.1 Direct Sequence Spread Spectrum (DS-SS) Communication

This is the widely used spread spectrum technique. The bandwidth spreading is accomplished by mixing the
narrowband information data with wideband noise-like pseudo-random signals as shown in Fig. 2. These wideband signals are random in nature but still has deterministic characteristics. They are also called as PN Sequences. The spreaded signal is BPSK modulated, amplified and transmitted. The radiated signal looks like a noise and therefore can not be detected easily by surveillance receiver. The intended receiver demodulates the information data by multiplying the received signal by same carrier and PN sequence. The phase and frequency of locally generated signal should be same as that of transmitter.

It is described by following relation.

\[
G_{p} = 10 \log \left( \frac{\text{Code Length}}{\text{Data Bit Rate}} \right) \text{ dB}
\]

The entire strength of spread spectrum technique lies in the process gain. The process gain further characterized by following equation.

\[
G_{p} = \frac{A}{J} + \frac{E_{b}}{N_{0}} + L
\]

Where, \(G_{p}\) → Processing Gain, \(A/J\) → Anti-Jam Margin, \(E_{b}/N_{0}\) → minimum required output signal to noise ration per bit and \(L\) → system implementation loss.

For Binary Phase Shift Keying (BPSK) the \(E_{b}/N_{0}\) is 10.6 dB and implementation loss is 3 to 4 dB. If code length of 1023 selected, then the process gain \(G_{p}\) is 30 dB and system anti-jam margin becomes 15 to 16 dB.

The PN sequences can be m-Sequences, Gold Codes, Kasami Codes, Barker Codes or Walsh Codes. The code length and type of code is selected based upon system requirement. If pure spread-spectrum with only anti-jam performance is required then m-Sequences or Barker codes can be used because of their excellent auto-correlation properties. However, Gold codes and Walsh sequences are used for multiple access requirements because of their good cross-correction properties.

**5.1.2 Frequency-Hopping Spread-Spectrum (FH-SS) Communication**

The simplest form of FH-SS is shown in Fig. 4. In FH-SS technique the frequency of transmission is hopped in a pseudo-random fashion. The frequency of transmission is randomly generated by frequency synthesizer as controlled by PN code. The information data is FSK modulation first in transmitter. The FSK signal is up-converted by random frequencies generated by synthesizer. In the receiver the frequency down-conversion is done by same set of random frequencies and subsequently FSK demodulation is performed.

The DS-SS has the advantage of providing higher capacities than FHSS, but it is a very sensitive technology, influenced by many environment factors such as multipath and near-far problem. The DS-SS is used for point to multipoint communication for short distances applications and point to point communication for long distance applications. On the other hand, FHSS is a very robust technology, with little influence from noises, reflections, other radio stations or other environment factors. In addition, the number of simultaneously active systems in the same geographic area (collocated systems) is significantly higher than the equivalent number for DSSS systems. All these features make the FHSS technology widely useful in missile applications.
5.2 HIGH SPEED WIRELESS COMMUNICATION SYSTEMS

5.2.1 Multi-Carrier Communication Systems (OFDM)

The aim is to split high speed data stream into large number of parallel streams of reduced data rate and transmit each on a separate orthogonal sub-carrier. The process is described in Fig. 5. This technique is known as orthogonal frequency division multiplexing (OFDM). The operation of multiplying the low data rate streams by orthogonal sub-carriers is equivalent to IFFT operation. However, a reversed action i.e. FFT is needed in receiver.

5.2.2 Multi-carrier CDMA (MC-CDMA)

The OFDM technique is designed basically to achieve very high data rate communication with signal processing carried out at low data rates. The technique provides an excellent performance in frequency selective fading. But lack of signal security and poor anti-jam performance are the major drawbacks. To overcome these drawbacks a combination of spread-spectrum and OFDM is used. The resultant system is multi-carrier CDMA system. The block diagram of MC-CDMA is given in Fig. 7.

The multi-carrier CDMA is a combination of spread-spectrum and multi-carrier technique. This system employs a set of large number orthogonal spreading codes and less number of orthogonal carriers in contrast to OFDM. Because of spreading codes the system provides relatively better anti-jam performance. The high speed data is converted into low speed data streams which are spreaded by codes followed by orthogonal sub-carrier modulation.

5.2.3 Multi-Code Communication System

The multi-Code CDMA system uses the parallel transmission, in which the transmitted high-speed serial data is converted to slow parallel data streams in several channels and modulated by orthogonal codes. So, the orthogonality is an important factor in implementing efficient signal multiplexing. Orthogonality is realised up by orthogonal codes generated by Walsh-Hadamard matrix which is shown in following equation.

\[ H_k = \begin{bmatrix} H_{k1} & H_{k2} \\ H_{k3} & H_{k4} \end{bmatrix} \]

The structure of Multi Code-CDMA system is shown in Fig. 8, and transmitted signal can be expressed by following equation.

\[ s(t) = \sum_{j=1}^{k} d_j \cdot w(j) \cdot \cos \omega_c t, \]

where \( w(j) = \pm 1 \)

The incoming data bits with bit duration \( T_b \) are serial-to-parallel converted into \( k \) parallel bit streams with symbol duration \( T = kT_b \). After the serial-to-parallel conversion, the symbols on each low-rate branch are modulated using...
back, which can be used for slaving the tracking system. The down-link can also be used for video transmission purpose in which missile borne Camera video or IR Seeker video can be transmitted.

The launching platform and missiles both use trans-receiver on them. The up and down link can be either half duplex or full duplex.

6.2 Non line of Sight Communication Links

The point-to-point links are line of sight links. The link works if a proper line of sight between transmitter and receiver exists. But there are situations when line of sight does not exists. Under such circumstances the intermediate nodes (repeaters(R)) are used to establish communication between nodes without line of sight. The repeaters can stationary or mobile elements and the individual links are always line of light.

6.3 Ad-hoc Networks

A typical broadcast network is shown in Fig. 11. Such a network is often required when multiple missiles are launched from a single launching platform. The network management is done by launching pad transmitter node which acts as a master. Other nodes are passive receivers on missiles. They operate in slave mode. The communication is done in highly time synchronized manner under the tight supervision and control of master node using command-response protocol. The network works in broadcast mode of communication.

Fig. 9 (b) is a two way RF link. The two way communication link consist of up and down links. The up link is used for target or command update and down link is used for multiple purpose. The down link may give navigation data back to ground which can processed at faster speed and results can be given to missile via up-link. The result can be mathematical data or can be in the form of commands. The down link can be used to give missile navigation data

Figure 8. Multi-Code CDMA technique.

6. MISSILE APPLICATIONS

6.1 Point-to-Point Communication Links

The point-to-point RF links are widely used in most of civilian and military communications because of portability and simplicity. The general form of point-to-point link is given in Fig. 9(a) and Fig. 9(b).

Fig. 9 (a) is a typical one way link. The one way communication links are often used for providing target or command update in missiles. Mainly data is transmitted from launching platform to the missile. These links may be surface-to-air, ship-to-air or air-to-air communication systems. Transmitter is mounted on launcher and receiver is mounted on missile. They are the simplest form but widely used links.

(a) One way link

(b) Two way link

Figure 9. Point-to-point RF links.

Both way communication is possible in this arrangement by using a trans-receivers in each node. A proper handshaking protocol is required for handling two way communication. Generally, the network use half-duplex communication in time division duplex mode. The time slots for each nodes should be properly identified and controlled by communication protocol.

Figure 10. Non line of sight communication.

Figure 11. Broadcast networkF links.
The following example is another form of ad-hoc network. Mostly for air to air attack the fighter aircrafts move in formation with some sort of ad-hoc communication network within them. When a missile is launched it also becomes a part an ad-hoc network. This arrangement helps if a parent aircraft fails to communicate with missile. The parent aircraft gives a hands-off to the other aircraft which subsequently communicates with missile.

![Figure 12. Ad-hoc network.](image)

7. IMPLEMENTATION

The spread-spectrum based data links have been developed, evaluated and validated in flight trials. A 2-channel 9.6 kbps X-band data link with 1023 length Gold Code is realized for air-to-air operation.

Similar links with data rate of 19.2 kbps and 38.4 kbps with Gold codes of 1023 and 127, respectively are also developed. Both the links are developed in L-Band and used for ground-to-air operation.

The code of length of 127 gives process gain of 21.03 dB with the anti-jam margin of 11 dB and code of length of 1023 gives process gain of 30 dB with the anti-jam margin of 17 dB. All the links are developed with programmable forward error correction capacity. The convolution encoding, decoding schemes with the coding gain of 4.5 dB are used. The data verification is done using CRC-16 algorithm in application level. Additional data encryption is provided for data security.

The performance of all above links is validated by conducting aircraft sorties and missile flight trials. The satisfactory and consistent performance is found in all the links.

Recently, a two way UP-DOWN command-video link is proposed for air-to-air operation. The command up link is 9.6 kbps use DS-SS communication. The video down link is 4 Mbps use linear FM technique. The preliminary design is completed and system realization is in progress.

8. CONCLUSION

Implementation of data-links in missile scenario is a complex activity. The challenges are of different form. The communication system needs to work reliably in extremely noisy conditions and under severe interference conditions. The missile dynamics, roll and plume also makes the condition extremely worst.

The spread spectrum techniques with high process gain is one solution. The DS-SS and FH-SS systems are widely accepted worldwide in missile communication. A DS-SS technique provide anti-jam capabilities by LPI/LPD signal characteristics. The BPSK modulation is used which gives a suppressed carrier system and therefore transmit power can be efficiently used. The FH-SS system provides anti-jam capability by hopping the frequency in random fashion. A appropriate technique should be selected and used.

The high data rate system can be realized by multi-code CDMA technique. The data rate of up to 5 Mbps with process gain of 21 dB and anti-jam margin of 12 dB can be realized. Two level of data modulation is performed. The orthogonal Walsh Codes for spreading is followed by PN code modulation for synchronization used. This technique can be used for video transmission from missile-to-ground because of relatively low transmit power consumption.

The high data rate system can be realized by OFDM and MC-CDMA technique. The OFDM system use large set of sub-carriers and data rate up to 50 Mbps is supported. The problem of OFDM of needs a pilot signal and it is very very sensitive to the doppler shifts. The doppler shifts may affect the orthogonality within the sub-carriers. Moreover, it does not have any anti-jam capabilities. Therefore it is not desirable to use in missile systems.

The MC-CDMA systems can be used because of less no of sub-carriers and therefore have less doppler effect. The system use Walsh codes and PN sequences and therefore, provide anti-jam capabilities. The MC-CDMA can support the moderate data rate up to 10 to 15 Mbps.

Thrust is now to have a software defined-configurable data link systems with features of technique, coding, spreading and detection logic which would will be programmable.