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Performance evalutation of wireless WIT2410 radio frequency transceiver used in AMIGO

(Autonomous MIcrosystems for Ground Observation)

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Defence R&D Canada – Valcartier
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The work was supported under Work Breakdown Element 12pa12 (was 12kc12) entitled "Autonomous Micro Sensors". The experimental results in this memorandum were conducted at DRDC Valcartier between the 11 and 26 March 2004.

Abstract

The objective of project AMIGO (Autonomous MIcrosystems for Ground Observation) is to develop a proof-of-concept, low-cost, compact unattended ground sensor suite that can provide the CF with real-time situational awareness from remote locations. Two of the major components in AMIGO are the RF transceiver and antennas for wireless communication that must provide reliable connectivity between the base station and each remote unit in any battlefield conditions. The transmission scheme should also be low probability of detection and interception (LPD/LPI). After a rigorous selection process, the RF transceiver WIT2410 was chosen for this R&D work.

The WIT2410 (Wireless Industrial Transceiver) from Cirronet can provide wireless connectivity in point-to-point or point-to-multipoint applications. The frequency hopping spread spectrum technology of the WIT2410 ensures maximum noise resistance, multi-path fading immunity, robustness in presence of interfering signals, LPD and LPI. In this work, different types of antennas and antenna configurations were tested with the transceivers at various locations of DRDC Valcartier. The RF signal strengths were recorded and compared. With this information, one can determine the WIT2410 limitation, reliability, and achievable range in different settings.

With the transceiver set at 100 mW RF output power, the best signal strength-to-distance was obtained using the Cirronet 2 dB dipole antenna (RWA249R) for the remote sensors located both indoors and outdoors at ground level and the Cirronet 9 dB omnidirectional antenna (OMNI249) for the base station located on an elevated position. With line of sight (LOS), reliable transmission between the remote sensor and the base station was obtained up to 1500 m. With non-line-of-sight (NLOS) scenarios varying from obstructions of a few trees to multiple buildings, the range of reliable transmission was averaged at about 450 m.

According to this result and understanding the transceiver limitation, one could deploy a wireless network sensor suite efficiently and reliably in open field and urban operations.

Résumé

L'objectif du projet AMIGO (Autonomous Microsystems for Ground Observation) consiste à mettre au point un démonstrateur technologique pour un prototype de système de surveillance compact intégré. Ce système comprend plusieurs capteurs intégrés pouvant fournir des informations à distance et en temps réel sur la situation aux forces canadiennes (FC). Deux des principaux composants d'AMIGO sont les émeteurs-récepteurs RF et les antennes utilisés. Ceux-ci doivent fournir aux FC un contact radio fiable entre chaque unité et la station-mère en toutes situations. Dans un contexte militaire, le protocole de transmission doit être fiable et le lien RF avoir une faible probabilité de détection et d'interception. Après un processus de sélection vigoureux, le émetteur-récepteur WIT2410 de Cirronet a été choisi pour ce travail de recherche et développement.

L'émeteur-récepteur WIT2410 (Wireless Industrial Transceiver) de Cirronet peut fournir un lien sans fil pour des applications point-à-point et point-à-multipoint. La technologie du saut de fréquence à spectre étalé (frequency hopping spread spectrum) du WIT2410 assure une résistance maximale au bruit, à l'évanouissement dû aux trajets multiples, aux signaux de brouillage et enfin, une très faible probabilité de détection et d'interception. Dans ce travail, différentes antennes et configuration d'antennes seront testées avec le émetteur-récepteur et pour différentes positions à l'intérieur du périmètre du centre de recherches. La puissance du signal reçu a été enregistrée et comparée. Avec ces informations, nous sommes en mesure de déterminer les limites du WIT2410, sa fiabilité et sa portée selon différentes configurations d'antennes.

Avec l'émetteur-récepteur configuré pour une puissance de transmission de 100 mW le meilleur rapport signal vs distance a été obtenu en utilisant l'antenne omnidirectional de 9 dB (OMNI249) pour la station-mère et l'antenne de 2 dB (RWA249R) pour les unités individuelles d'AMIGO. Avec une ligne de vue directe sans obstruction, une transmission fiable entre les unités d'AMIGO et la station mère a été obtenue jusqu'à 1500 mètres. Avec différents niveaux d'obstruction dans la ligne de transmission RF par des édifices et des arbres, on a obtenu un lien fiable entre les unités et la station-mère sur une distance de 450 mètres. La portée avec une unité AMIGO localisée à l'intérieur d'un édifice est évaluée à 200 mètres.

Finalement, en s'appuyant sur les résultats obtenus, et en tenant compte des limitations des émetteurs-récepteurs, il est possible de déployer un réseau de capteurs sans fils efficacement et fiablement dans les espaces ouverts et les milieux urbains.

Executive summary

There is a need to collect field information for surveillance or action preparation purposes in today's military activities. Nowadays, these operations are carried out by personnel or by air surveillance with various expensive, sophisticated sensors. Moreover, these monitoring operations are difficult to maintain in volatile situations and the cost of continuous surveillance is high. Not only such a deployment is risky, it is time consuming to prepare, coordinate, and perform. Therefore, there is a need to develop low-cost sensors, which collect and report field information to the base autonomously. This is the motivation behind the concept of Autonomous MIcrosystems for Ground Observation (AMIGO) currently investigated at DRDC Valcartier.

The objective of AMIGO is to develop a proof-of-concept, low-cost, compact unattended ground sensor suite that can provide real-time situational awareness from remote locations. It is obvious that a reliable wireless transmission must be maintained at all times between the base station and each remote unit for information exchange in any battlefield conditions. The transmission scheme should also be low probability of detection and interception (LPD/LPI). This is the reason that two of the major components in AMIGO are the wireless transceiver and antennas.

The overall performance of a wireless network depends not only on the quality of the transceivers but also on the types of antennas used in the network. Therefore, it is important to choose and match the transceiver and antennas accordingly for optimum performance. A wireless transceiver and different types of antennas were selected for testing which was carried out at various locations and distance ranges at DRDC Valcartier. The RF signal strengths were recorded and compared. With this information, one can determine the current wireless network limitation, reliability, and achievable range in different settings.

With the transceiver set at 100 mW RF output power, the best signal strength-to-distance was obtained using a dipole antenna for the remote sensors located both indoors and outdoors at ground level and an omnidirectional antenna for the base station located on an elevated position. With line-of-sight (LOS), reliable transmission between the remote sensor and the base station was obtained up to 1500 m. With non-line-of-sight (NLOS) scenarios varying from obstructions of a few trees to multiple buildings, the range of reliable transmission was averaged at about 450 m. The range of reliable transmission inside a Building is estimated to about 200 m.

According to this result and understanding the transceiver limitation one could deploy a wireless network sensor suite efficiently and reliably both in open field and urban operations. Since the finding here is generic to all wireless network transmission systems, it is also useful to other R&D projects using wireless links.

D. Comeau, P. Laou, L. Durand. 2004. Performance evaluation of wireless WIT2410 radio frequency transceiver used in AMIGO. DRDC Valcartier. TN 2004-050.

Sommaire

Dans les activités militaires d'aujourd'hui, il est de plus en plus nécessaire de recueillir des informations à jour sur le champ de bataille. De nos jours, ces opérations de surveillance sont effectuées par du personnel dans les airs et sur terre avec l'aide d'équipements sophistiqués et dispendieux. Cette surveillance est difficile à maintenir dans des situations changeantes et les coûts associés à cette surveillance continue sont élevés, risqués et très exigeants au point de vue de temps de préparation, de coordination et d'exécution. Par conséquent, il existe un besoin opérationnel pour des capteurs à faible coût qui peuvent recueillir et rapporter toute information sur la situation de la scène de façon autonome. Ceci est la motivation derrière le concept d'AMIGO (Autonomous MIcrosystemes for Ground Observation (AMIGO) que l'on est présentement à mettre au point à RDDC Valcartier.

L'objectif d'AMIGO consiste à mettre au point un démonstrateur technologique de système de surveillance compact intégré pouvant fournir aux Forces canadiennes des informations en temps réel sur la situation opérationnelle. Il est évident qu'une transmission sans fil fiable doit être maintenue en tout temps entre la station-mère et les unités d'AMIGO. Dans le contexte militaire, le protocole de transmission RF doit avoir une faible probabilité de détection et d'interception. Ce sont les raisons pour lesquelles deux des composants majeurs dans AMIGO sont les émetteurs-récepteurs WIT2410 et les antennes.

La performance globale d'un réseau sans fil est non seulement liée à la qualité de l'émetteur-récepteur, mais aussi du type d'antenne utilisée. Par conséquent, il est important de sélectionner et d'agencer les antennes en accord avec les performances optimales respectives de chaque antenne. L'émetteur-récepteur WIT2410 utilisé dans AMIGO a donc été testé selon différentes configurations d'antennes et localisations. La puissance RF du signal reçu a été enregistrée et comparée. Avec ces informations, nous sommes en mesure de déterminer les limites du WIT2410, sa fiabilité, et sa portée selon différentes configurations.

Avec l'émetteur-récepteur configuré pour une puissance de transmission de 100 mW. On a obtenu le meilleur signal-distance en utilisant l'antenne omnidirectionelle de 9 dB (OMNI249) pour la station mère et l'antenne de 2 dB (RWA249R) pour les unités individuelles d'AMIGO. Avec une ligne de visée directe sans obstruction jusqu'à 1500 mètres, une transmission fiable entre les unités d'AMIGO et la station-mère. Avec différents niveaux d'obstruction dans la ligne de visée RF par des édifices et des arbres, on a obtenu un lien fiable sur une distance de 450 mètres.

Finalement, en s'appuyant sur les résultats obtenus, et en tenant compte des limitations des émetteurs-récepteurs, il est possible de déployer un réseau de capteurs sans fils efficacement et fiablement dans les espaces ouverts et les milieux urbains. Enfin, étant donné que les informations présentées ici s'appliquent à d'autres systèmes RF, celles-ci pourront aussi servir dans d'autres projets de recherche et développement.

D. Comeau, P. Laou, L. Durand. 2004. Performance evaluation of wireless WIT2410 radio frequency transceiver used in AMIGO. RDDC Valcartier. TN 2004-050.

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Introduction

There is a need to collect field information for surveillance or action preparation purposes in today's military activities. Nowadays, these operations are carried out by personnel or air surveillance with various expensive, sophisticated sensors. However, the large volume of collected data makes it difficult to extract timely interpretations for decision making in time-critical scenarios. In addition, as the activity is occurring, it is almost impossible to retask the system to resolve ambiguity in the original data. Moreover, these monitoring operations are difficult to maintain in volatile situations and the cost of continuous surveillance is high. Not only such a deployment is risky, it is time consuming to prepare, coordinate, and perform. Therefore, there is a need to develop low-cost sensors, which collect and report field information to the base autonomously. This is the motivation behind the concept of Autonomous Microsystems for Ground Observation (AMIGO) currently investigated at DRDC Valcartier. This work is to establish preliminary standard; to design and manufacture prototype microsystems; and to identify strategies and directions for further improvement of the units. These systems differ from their counterparts in that they are mission specific, so that the reduced demand in sensing robustness and versatility is translated into simpler, computationally less demanding systems.

AMIGO is intended for use in open terrain or urban operations for locating, counting, and classifying time-critical targets. It consists of a number of AMIGO units that gather, put in storage, and transmit time-critical images of a remote location to a computer or base station with wireless RF link. It is obvious that a reliable wireless transmission must be maintained at all times between the base station and each remote unit for information exchange in any battlefield conditions.

The overall performance of a wireless network depends not only on the quality of the transceivers but also on the types of antennas used in the network. Therefore, it is important to choose, and match the transceiver and antenna accordingly for optimal performance. The goal of the current technical memorandum is to present the testing results of the RF communication in AMIGO. In this work, a wireless transceiver and different types of antennas were selected for testing which was carried out at various locations and distance ranges at DRDC Valcartier and CFB Valcartier. The RF signal strengths were recorded and compared. With this information, one can determine the transmission limitation, reliability, and achievable range in different settings.

This work was supported under Work Breakdown Element 12pa12 (was 12kc12) entitled "Autonomous Micro Sensors". The experimental results in this report were conducted at DRDC Valcartier between March 11 and March 26 2004.

Hardware

The following is a description of the selected hardware in this work and their specifications.

Transceiver

The WIT2410 (Wireless Industrial Transceiver) from Cirronet can provide wireless connectivity for either point-to-point or point-to-multipoint application. The frequency hopping spread spectrum technology of the WIT2410 ensures maximum noise resistance, multi-path fading immunity, robustness in presence of interfering signals, and LPD and LPI. Here is a list of the specifications according to the manufacturer.

- simple serial interface handles 230.4 kbps
- transparent ARQ protocol 3 k buffer to ensure data integrity
- superior range (in theory up to 43 km) for LAN device
- built-in scrambling reduces possibility of eavesdropping
- meets FCC rules worldwide
- small size (80 mm × 46 mm × 8 mm)
- smart power management (22 mA in standby mode)
- digital addressing supports up to 64 networks
- support diversity of antennas
- non-volatile memory stores configuration when powered off
- low power 3.3 V CMOS signals
- selectable RF output power between 10 mW and 100 mW

The WIT2410 uses Ethernet protocol 802.11 which refers to a family of specifications developed by the IEEE for wireless local area network (LAN) technology. The 802.11 specify an over-the-air interface between a wireless client and a base station or between two wireless clients. The IEEE accepted the specification in 1997. As the next generation 802.11b and 802.11g are becoming available and popular, these improved protocols will be considered in future developments.

Transceiver interfacing to serial port

For the base station, the interfacing of the WIT2410 Cirronet transceiver (Figure 1) with the PC serial port was achieved using a circuit recommended by the transceiver manufacturer (Figure 2). This circuit receives and transmits the ±12 V serial streams of data from the PC serial port and the logic 0/3.3 V compatible of the transceiver. A 2×8 Samtec cable was used to connect the transceiver to the circuit.

Figure 1. WIT2410 transceiver

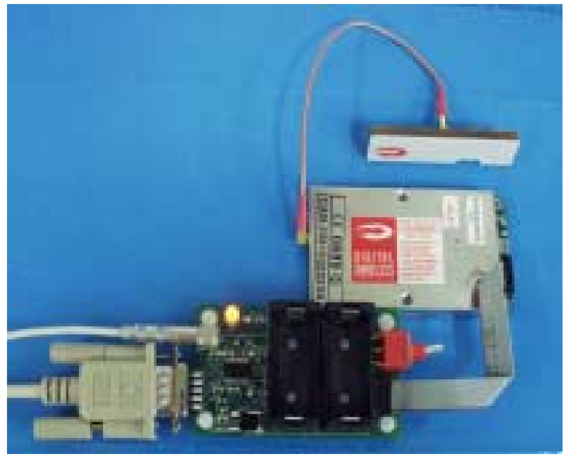

Figure 2. WIT2410 serial port transceiver interface

Antenna identification

In the experiment, four different Cirronet antennas were selected and tested. For the base station, the two antennas are the 9 dB omnidirectional OMNI249 and the directional 9 dB CORNER249 (Figures 3 and 4). For the remote units, the two antennas are: the 6 dB micro-strip or patch antenna PA2400 and the 2 dB Cirronet dipole RWA249R (Figures 5 and 6). Table 1 summarizes the specifications of the antennas.

Figure 3. Cirronet 9 dB omnidirectional antenna

Figure 4. Cirronet 9 dB corner reflector antenna

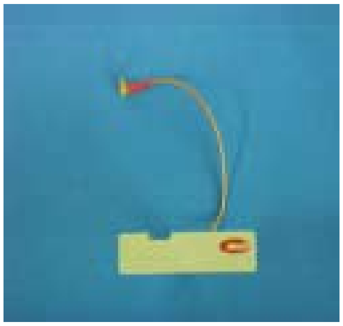

Figure 5. Cirronet 6 dB patch antenna

Figure 6. Cirronet 2 dB dipole antenna

Table 1. Cirronet antenna identification and part number

DESCRIPTION	GAIN	PART NUMBER	REF. NAME	COUPLING
Cirronet 9 dB Omnidirectional	9 dB	OMNI249	Omni	N
Cirronet 9 dB Corner Reflector	9 dB	CORNER249	Corner	N
Cironnet 6 dB Patch	6 dB	PA2400	Patch	MMCX
Cironnet 2 dB Dipole	2 dB	RWA249R	Dipole	Reverse SMA

Antenna coupling to base station transceiver

The two base station antennas (omnidirectional and corner reflector) could not be connected directly to the transceiver due to a connector mismatch. To overcome this problem, two custom-made 50 Ω cables with the appropriate connectors on both sides were fabricated. As shown in Figure 7, a plastic box was used to house the serial port interface circuit and the transceiver (Figure 2). A six-inch RG-174 cable was made with a MMCX connector and a TNC connector at each end. The TNC connector was exposed outside the plastic box. Then a six-feet RG-58 cable was fabricated with a TNC connector to be connected to the box and an N connector to be connected to the two base station antennas (Figure 8). With these two cables, the base station box and its antenna were link. Finally the base station through a RS-232 cable (DB9M/DB9F) was connected to the serial port of the base command computer. External power supply was used to provide the 6 V needed by the serial port transceiver interface circuit.

Figure 7. Base station box enclosure and serial port interface circuit

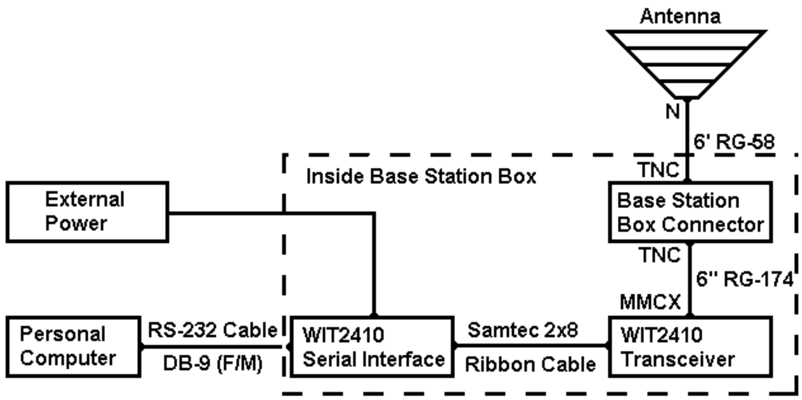

Figure 8. Block diagram of the base station interfacing

Antenna mounting to remote units

Both Cirronet patch and dipole antenna can be coupled directly to the transceivers of the remote units using a single RG-174 cable with MMCX connectors (same as shown in Figure 2). The antennas have the appropriate RG-174 cable with MMCX plug-in. The remote transceiver was enclosed inside the remote unit. The 6 dB Cirronet patch was mounted horizontally, while the dipole antenna was mounted vertically outside the remote unit (see Figure 9).

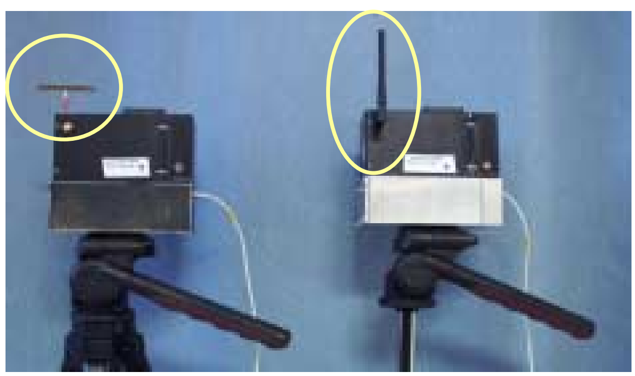

Figure 9. Remote antenna mounting

Experimental setup and procedure

To test the RF link reliability, series of signal strength measurements were made at various locations near DRDC Valcartier (north side) and at CFB Valcartier with different antennas and configurations.

Signal strength measurement

To measure the received signal strength, an integrated command called Read Receive Signal Strength was used. This command functions only work when the WIT2410 is configured as a remote. Upon receiving of the command, the transceiver returns the signal strength value which is between 00(HEX) and FF(HEX). Typical range is from 30(HEX) to 80(HEX). At the base station, all values received between 30(HEX) to 80(HEX) were linearly translated to 0 % to 100 %. In the experiments, when the signal strength is below 25 %, as the signal strength is inversely proportional to lost data packets during transmission, it is not possible to transfer data reliably such as an image. The 25 % value will be used to determine as the baseline of the transmission range limit.

Range optimization setting

A second command can be used for range optimization. This results to an adjustment factor to compensate the effects of propagation delay at long ranges. A value is send to the transceiver between 00(HEX) and FA(HEX) for optimized transmission between 200 m to 43 km (see Table 2). The default value is 00(HEX) that represents an optimal range of 200 m and a maximum range of 1.3 km. With the knowledge of the distance between the base station and remote unit, efforts were made to keep the range setting value as close to the optimize range setting.

Table 2. Transceiver setting for various distances

SETTING (HEX)	RANGE MIN (km)	RANGE OPTIMAL (km)	RANGE MAX (km)
00H	0	0.2	1.3
01H	0	0.3	1.5
04H	0	0.8	2.0
06H	0.2	1.2	2.3
09H	0.7	1.6	3.0
13H	2.3	3.3	4.7
31H	7.3	8.3	9.7
45H	10.7	11.7	13.0
64H	15.7	16.7	18.0
C8H	32.3	33.3	34.7
FAH	40.7	41.7	43.0

Antenna setup of base station and remote unit

For the base station, both OMNI249 and CORNER249 antennas were tested. The CORNER249 horn was mounted in both horizontal and vertical orientation (Figures 10 and 11) in order to determine the best orientation. Two remote units were deployed. One unit was equipped with the PA2400 (Figure 5) antenna while the second one with the RWA249R (Figure 6).

Figure 10. Horizontal orientation of the CORNER249 (Vertical polarization)

Figure 11. Vertical orientation of the CORNER249 (Horizontal polarization)

Measurement location and procedure

The first set of measurements was performed to test the RF link reliability in a near urban environment at DRDC Valcartier. In this measurement, the base station was located on top of Building 25 at DRDC Valcartier while the two remote units were moved to various locations. Ten locations (R1 to R10) were selected (Table 3). These locations are inside DRDC Valcartier with various LOS/NLOS scenarios such as short-range and long-range LOS and obstructions by trees and buildings, etc. For the base station four locations BS1 to BS4 were selected (Table 4). With a GPS, these locations were recorded in UTM and shown in Tables 4 and 5. Different locations of the remote (R1 to R10) and base station (BS1 to BS3) are visually shown in Figure 12.

Table 3. UTM coordinate of remote unit locations R1 to R10

LOCATION	UTM (ZONE 19T)		
LABEL	NORTH	EAST	NOTE
R1	5195274	311025	Inside Building 14
R2	5195277	311048	Outside Building 14 with no major obstacles blocking LOS
R3	5195343	311046	Twice the distance of R2 and LOS blocked by Building 14
R4	5195427	311012	Twice the distance of R3 and LOS blocked by Building 15
R5	5195753	311895	LOS 500 m (Farthest point in Lemay Park)
R6	5195570	310785	LOS 350 m (blocked by trees)
R7	5195244	310886	Behind Building 24 and LOS blocked by Buildings 25 and 24
R8	5195059	311390	LOS 400 m and behind Building 83 (Transport)
R9	5195265	311077	Outside and LOS completely blocked by Building 53
R10	5195306	311131	Outside and LOS completely blocked by Buildings 53 and 122

Table 4. UTM Coordinate of the base station location BS1 to BS4

LOCATION	UTM (ZONE 19T)		
LABEL	NORTH	EAST	NOTE
BS1	5195223	310994	On top of Building 25 next to the space telescope
BS2	5195230	310963	On top of Building 25 above Local 302 (Jean-Marc Thériault laboratory)
BS3	5195230	310963	Third floor of Building 25 inside Local 302 (Jean-Marc Thériault laboratory)
BS4	5198585	307301	At the beginning of precision firing range at CFB Valcartier

In the second set of measurements, the impact on signal strength of indoor transmission was studied. The remote units and the base station were moved inside buildings. The third set of measurements was carried out at the precision firing range of CFB Valcartier. At this location, there is a 100 m by 2.5 km long corridor with no major obstacles. At every 100 m, 10 readings were recorded for each remote. This test was repeated until it was no longer possible to communicate with each remote unit.

The remote units were mounted on a three feet tripod. Remote unit number 3 was equipped with the 2 dB dipole antenna RWA249 R while remote unit number 4 was equipped with the 6 dB Cirronet patch PA2400 (Figure 9). As the remote units were moved to a new predefined test points (R1 to R10 in Figure 11) or at every 100 meters along the 100 m by 2.5 km corridor, the received signal strength reading from each remote unit was recorded. At every location, image transfer test was executed to verify the reliability of the RF link. There is a command implemented in each remote that can generate a test image and send remotely that image to the base station. A successful download is an indication of good RF link reliability since 120 packets of 170 bytes are sent consecutively for one single image of 120 by 160 pixels. The results of these images transfer tests are shown in ANNEXS A to C. A “Y” meaning a successful download was achieved and “N” an unsuccessful download attempt.

Figure 12. Aerial view showing the remote units and base station locations

Results and discussion

The RF transmission result of the signal strength testing in a near urban environment at DRDC Valcartier was summarized in Table 5. The signal strength was measured using different antennas for the base station and remote unit and at various remote unit locations. Each value summarized in Table 5 is the result of the averaging of 10 readings of the signal strength.

Table 5. Result of the average received signal strength at different outside locations

REMOTE	PATCH			DIPOLE		
	BASE STATION (Top of Bdg. 25)			BASE STATION (Top of Bdg. 25)		
LOCATION	Omni	Corner V	Corner H	Omni	Corner V	Corner H
	(%)	(%)	(%)	(%)	(%)	(%)
R1	27.5	39.4	29.5	49.1	48.3	50.9
R2	38.0	63.0	51.5	62.9	71.5	86.4
R3	54.8	52.2	46.3	55.0	51.5	56.1
R4	27.8	28.6	27.7	47.6	42.6	45.8
R5	41.9	42.1	35.5	68.5	56.6	65.3
R6	22.3	35.3	40.4	41.0	48.1	47.0
R7	30.6	33.8	28.1	48.2	44.3	45.5
R8	0.0	0.0	0.0	32.7	0.0	0.0
R9	33.4	47.4	34.3	50.4	44.2	51.5
R10	26.5	34.8	26.8	48.2	38.1	42.3
Average	**30.3**	**37.7**	**32.0**	**50.4**	**44.5**	**49.1**

According to Table 5, it is clear that the highest signal strength could be obtained with the 9 dB omnidirectional antenna at the base station and the dipole antenna at the remote unit. The corner antenna oriented vertically or horizontally also provided acceptable signal strength. The dipole antenna provides 15 to 25 % more signal strength than the patch antenna in an urban environment. At all locations R1 to R10, image transfers were successful when using the dipole for the remote and the 9dB omnidirectional for the base station. It is noted that the weakest signal strength was at location R8. This is due to the fact that there were multiple buildings in the RF signal path (NLOS) and the remote was located 450 m away and was completely behind Building 83 (Transport). Even with a relatively week signal strength reading at that location, a normal image transfer download was performed successfully. Therefore, it is safe to conclude that a reliable RF transmission can be obtained with an average range of 450 m in this urban environment under similar conditions.

In order to study the impact on transmission in an indoor environment, the two remote units were moved inside Building 14 for signal strength measurement. The result was illustrated in Table 6. It is noted that the dipole antenna was used for all remote units. The base station was also moved between indoor and outdoor on the top floor of Building 25.

Table 6. Effect of indoor transmission on the average received signal strength

REMOTE			BASE STATION		SIGNAL STRENGTH (%)					AVG.
					1	2	3	4	5	
Location	Antenna	Number	Location	Antenna						
R1 (IN)	Dipole	3	BS2 (OUT)	Whip	36.0	26.0	29.0	34.0	NA	31.3
R1 (IN)	Dipole	3	BS2 (OUT)	Corner H	37.6	29.8	26.3	27.5	32.5	30.7
R1 (IN)	Dipole	3	BS2 (OUT)	Corner V	25.1	31.4	22.4	29.8	17.6	25.3
R1 (IN)	Dipole	3	BS3 (IN)	Whip	18.0	12.0	23.0	21.0	16.0	18.0
R1 (IN)	Dipole	3	BS3 (IN)	Corner H	20.0	14.0	17.0	20.0	18.0	18.0
R1 (IN)	Dipole	3	BS3 (IN)	Corner V	3.0	5.0	10.0	2.0	8.0	7.0
R2	Dipole	4	BS2	Whip	48.0	52.0	58.0	54.0	NA	53.0
R4	Dipole	4	BS2	Whip	22.4	25.1	22.4	20.0	21.2	22.2
R5	Dipole	4	BS2	Whip	50.2	41.2	48.6	38.8	NA	44.7
R6	Dipole	4	BS2	Whip	26.3	22.4	25.1	20.0	20.0	22.8

It is clear that the signal strength was overall weaker than those shown in Table 5. With the remote unit inside a building, signal strength was reduced by approximately 15 %. It is understood that this value depends on many factors such as the numbers of windows, the building materials, reflection on the surrounding buildings and the building materials used, etc. Therefore, this value can be used only as a relative reference.

The final measurement was to determine the maximum transmission range under a near perfect LOS scenario. In this test, the average received signal strength from each remote unit at different distances was obtained. Each value presented in Tables 5 and 7 was obtained by averaging 10 readings of the received signal strength, while in Table 6 by averaging four to five readings. For the remote with the patch antenna, communication was lost beyond 600 m. It is noted that there was a truck partially blocking the RF link at the 500 to 600 m range. As a result, the signal strength taken at these distances could be less that the real LOS signal strength. On the other hand, a reliable transmission was obtained up to 1100 m with the use of the dipole antenna. Further beyond 1100 m, due to a slight inclination of the road, the receiver signal strength was weak and below 30 %. It was proven by the fact that a better signal strength was received by raising the remote tripod height. At 1200 m there was too many disconnection and reconnection packets that it was not possible to maintain transmission. To check if it was indeed the inclination of the road that affects the signal strength, the remote unit was moved 500 m further (at 1700 m) where the road elevation was higher. At this location, a reliable transmission was re-established. Three images were successfully transmitted and downloaded. This result shows that a long range RF transmission is possible in a near LOS scenario using low RF output power and gain antenna.

The average received signal strength values relative to the distance are illustrated in Figure 13. From a curve that best fit the data, it is clear that the received signal strength gets below 30 % beyond 1500 m. As mention earlier, 25 % is the baseline of the transmission reliability limit.

Table 7. Average received signal strength in LOS measurement

	BASE STATION		REMOTE LOCATION AND SIGNAL STRENGTH			
DISTANCE			UTM LOCATION (T19)		PATCH	DIPOLE
(m)	Location	Antenna	NORTH	EAST	(%)	(%)
0	B4	Whip	5198585	307301	78.2	86.9
100	B4	Whip	5198697	307297	37.6	69.0
200	B4	Whip	5198791	307293	35.0	69.1
300	B4	Whip	5198888	307289	28.5	57.0
400	B4	Whip	5198992	307295	27.3	53.1
500	B4	Whip	5199094	307272	24.3	46.4
600	B4	Whip	5199194	307269	22.0	40.7
700	B4	Whip	5199194	307260	NA	49.0
800	B4	Whip	5199396	307265	NA	43.9
900	B4	Whip	5199491	307260	NA	43.1
1000	B4	Whip	5199592	307266	NA	35.1
1100	B4	Whip	5199683	307262	NA	35.3
1700	B4	Whip	5200289	307227	NA	33.1

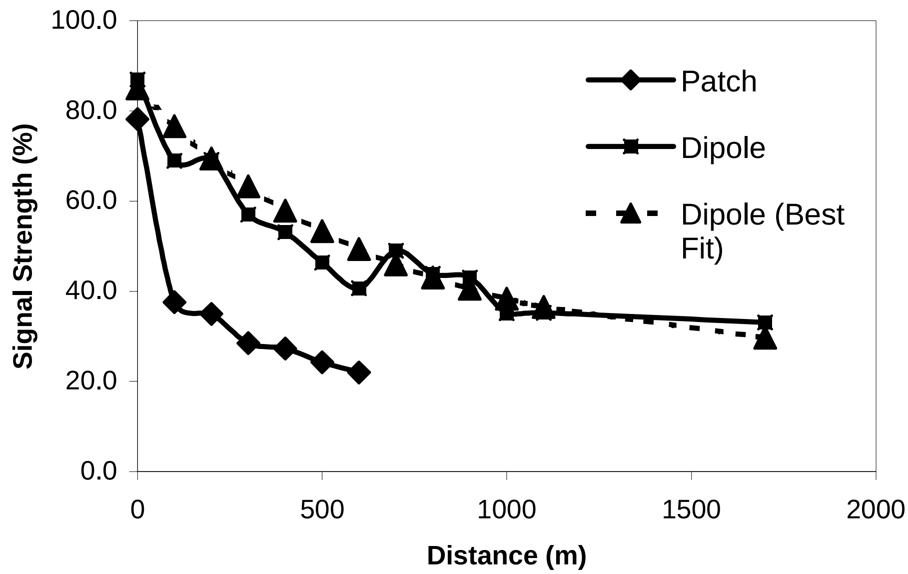

Figure 13. Average received signal strength vs distance

The 802.11 Ethernet protocol allows point-to-point and point-to-multipoint communication. In a point-to-multipoint mode, however, the overall performance of the entire network can drop by as much as 50 % when two remote units communicate simultaneously to the base station [2]. This is caused by signal interference and is part of a well-known problem called the hidden node problem. Under some rural conditions, this problem can significantly reduce the overall performance and can lead to a very low range. In addition, when buildings block the

LOS of some of the remote units, these units may not be able to communicate with the base station. One solution to this is to configure a hopping network communication (ad hoc), so that communication links from the blocked units can be routed around the obstacles and re-established reaching the base station [4]. Unfortunately, the 802.11 Ethernet protocol does not have this networking function. The next generation protocols such as 802.11b and 802.11g protocols allow enhanced network communication as well as higher baud rate [3]. The next generation protocols will be considered in the future project development when they are becoming available.

Conclusions

The overall performance of the AMIGO wireless communication was investigated in this work. Different antennas were tested to determine the optimal configuration. Measurements were performed in various scenarios such as LOS, partial LOS, NLOS, and indoor transmission.

With the transceiver set at 100 mW RF output power, the best signal strength-to-distance was obtained using a 2 dB gain dipole antenna for the remote sensors located both indoors and outdoors at ground level and an 9 dB omnidirectional antenna for the base station located on an elevated position. With LOS, reliable transmission between the remote sensor and the base station was obtained up to 1500 m. With partial LOS and NLOS scenarios varying from obstructions of a few trees to multiple buildings, the range of reliable transmission was averaged at about 450 m. When the remote sensor was located inside a building, the signal strength was reduced by an average of 15 %.

In addition, the corner antenna oriented vertically or horizontally also provided acceptable signal strength. The drawback of this type of antenna is that it is directional, i.e. it has to be pointed towards the remote units. This makes it less useful in urban deployment situation.

According to this result, one could deploy a similar wireless network sensor suite accordingly both in open field and urban operations for best achievable performance. Since the finding here is generic to many wireless network transmission systems, it is also useful to other R&D projects using wireless communication.

References

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Annex A: Experimental data acquired near DRDC Valcartier (R1 to R10)

Base Station		Remote			Received Signal Strength										Average	Note
Location	Antenna	Location	Num.	Antenna	(%)										(%)	
					1	2	3	4	5	6	7	8	9	10	Avg.	Image (Y/N)
BS1	Omni	R1	3	Patch	21.2	29.8	27.5	29.8	27.5	31.4	23.9	26.3	27.5	29.8	27.5	Yes
BS1	Corner V	R1	4	Dipole	50.2	53.7	43.9	38.8	47.5	57.6	40.0	43.9	51.4	56.1	48.3	Yes
BS1	Corner H	R1	3	Patch	28.6	31.4	21.2	32.5	33.7	29.8	34.9	22.4	31.4	28.6	29.5	Yes
BS1	Omni	R1	4	Dipole	48.6	51.4	56.1	42.4	45.1	45.1	53.7	48.6	52.5	47.5	49.1	Yes
BS1	Corner V	R1	3	Patch	40.0	43.9	41.2	37.6	41.2	46.3	18.8	40.0	45.1	40.0	39.4	Yes
BS1	Corner H	R1	4	Dipole	52.5	25.1	57.6	60.0	61.2	52.5	56.1	60.0	54.9	28.6	50.9	Yes
BS1	Omni	R2	3	Patch	52.5	45.1	38.8	42.4	42.4	33.7	32.5	31.4	41.2	34.9	38.0	Yes
BS1	Corner V	R2	4	Dipole	80.0	72.5	78.8	68.6	73.7	63.9	66.3	67.5	72.5	71.4	71.5	Yes
BS1	Corner H	R2	3	Patch	53.7	48.6	47.5	53.7	51.4	53.7	52.5	50.2	54.9	48.6	51.5	Yes
BS1	Omni	R2	4	Dipole	60.0	65.1	62.4	71.4	66.3	72.5	57.6	68.6	63.9	41.2	62.9	Yes
BS1	Corner V	R2	3	Patch	66.3	63.9	48.6	68.6	58.8	57.6	72.5	66.3	61.2	66.3	63.0	Yes
BS1	Corner H	R2	4	Dipole	86.3	82.4	85.1	86.3	86.3	86.3	86.3	91.4	91.4	82.4	86.4	Yes
BS1	Omni	R3	3	Patch	56.1	56.1	52.5	56.1	58.8	47.5	56.1	57.6	54.9	52.5	54.8	Yes
BS1	Corner V	R3	4	Dipole	45.1	48.6	56.1	52.5	53.7	57.6	51.4	56.1	46.3	47.5	51.5	Yes
BS1	Corner H	R3	3	Patch	43.9	41.2	51.4	38.8	34.9	51.4	47.5	50.2	52.5	51.4	46.3	Yes
BS1	Omni	R3	4	Dipole	60.0	58.8	62.4	57.6	60.0	47.5	46.3	40.0	61.2	56.1	55.0	Yes
BS1	Corner V	R3	3	Patch	52.5	52.5	54.9	52.5	52.5	52.5	53.7	45.1	52.5	53.7	52.2	Yes
BS1	Corner H	R3	4	Dipole	60.0	48.6	61.2	54.9	62.4	45.1	58.8	60.0	56.1	53.7	56.1	Yes
BS1	Omni	R4	3	Patch	22.4	27.5	26.3	33.7	28.6	33.7	29.8	28.6	20.0	27.5	27.8	Yes
BS1	Corner V	R4	4	Dipole	48.6	34.9	48.6	37.6	48.6	33.7	37.6	45.1	48.6	42.4	42.6	Yes
BS1	Corner H	R4	3	Patch	28.6	27.5	29.8	20.0	28.6	31.4	25.1	29.8	28.6	27.5	27.7	Yes (25 sec)
BS1	Omni	R4	4	Dipole	47.5	37.6	48.6	51.4	46.3	50.2	45.1	51.4	53.7	43.9	47.6	Yes
BS1	Corner V	R4	3	Patch	27.5	34.9	23.9	26.3	32.5	27.5	27.5	28.6	29.8	27.5	28.6	Yes (10 sec)
BS1	Corner H	R4	4	Dipole	48.6	45.1	50.2	43.9	45.1	46.3	50.2	51.4	43.9	33.7	45.8	Yes
BS1	Omni	R5	3	Patch	40.0	41.2	43.9	41.2	40.0	42.4	43.9	42.4	41.2	42.4	41.9	Yes
BS1	Corner V	R5	4	Dipole	60.0	57.6	56.1	51.4	57.6	56.1	54.9	56.1	52.5	63.9	56.6	Yes
BS1	Corner H	R5	3	Patch	40.0	33.7	38.8	33.7	31.4	38.8	31.4	40.0	36.1	31.4	35.5	Yes
BS1	Omni	R5	4	Dipole	66.3	66.3	63.9	69.8	71.4	72.5	69.8	69.8	65.1	69.8	68.5	Yes
BS1	Corner V	R5	3	Patch	36.1	37.6	42.4	43.9	42.4	47.5	38.8	41.2	45.1	46.3	42.1	Yes
BS1	Corner H	R5	4	Dipole	65.1	66.3	65.1	63.9	65.1	66.3	63.9	66.3	65.1	66.3	65.3	Yes

Experimental data acquired near DRDC Valcartier (R1 to R5)

Annex B: Experimental data acquired near DRDC Valcartier (R6 to R10)

Base Station		Remote			Received Signal Strength										Average	Note
Location	Antenna	Location	Num.	Antenna	(%)										(%)	Image (Y/N)
					1	2	3	4	5	6	7	8	9	10	Avg.	
BS1	Omni	R6	3	Patch	25.1	22.4	25.1	27.5	26.3	17.6	26.3	17.6	17.6	17.6	22.3	No
BS1	Corner V	R6	4	Dipole	45.1	50.2	47.5	48.6	46.3	51.4	45.1	52.5	46.3	47.5	48.1	Yes
BS1	Corner H	R6	3	Patch	42.4	36.1	41.2	37.6	40.0	42.4	43.9	40.0	37.6	42.4	40.4	Yes
BS1	Omni	R6	4	Dipole	33.7	40.0	50.2	34.9	43.9	46.3	42.4	37.6	38.8	42.4	41.0	Yes
BS1	Corner V	R6	3	Patch	26.3	31.4	43.9	33.7	40.0	26.3	41.2	40.0	41.2	28.6	35.3	Yes
BS1	Corner H	R6	4	Dipole	48.3	43.9	45.1	47.5	42.4	45.1	45.1	52.5	51.4	48.6	47.0	Yes
BS1	Omni	R7	3	Patch	34.9	27.5	28.6	23.9	26.3	37.6	36.1	18.8	36.1	36.1	30.6	Yes
BS1	Corner V	R7	4	Dipole	42.4	46.3	43.9	41.2	51.4	41.2	45.1	43.9	47.5	40.0	44.3	Yes (10 sec)
BS1	Corner H	R7	3	Patch	31.4	29.8	27.5	28.6	26.3	27.5	27.5	25.1	27.5	29.8	28.1	Yes (11 sec)
BS1	Omni	R7	4	Dipole	52.5	53.7	52.5	41.2	52.5	45.1	41.2	47.5	41.2	54.9	48.2	Yes
BS1	Corner V	R7	3	Patch	34.9	32.5	32.5	36.1	33.7	38.8	31.4	32.5	33.7	31.4	33.8	Yes (11sec)
BS1	Corner H	R7	4	Dipole	41.2	40.0	43.9	42.4	50.2	45.1	48.6	46.3	48.6	48.6	45.5	Yes (9 sec)
BS1	Omni	R8	3	Patch	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	No
BS1	Corner V	R8	4	Dipole	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	No
BS1	Corner H	R8	3	Patch	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	No
BS1	Omni	R8	4	Dipole	23.9	40.0	22.4	40.0	34.9	22.4	34.9	37.6	36.1	34.9	32.7	Yes
BS1	Corner V	R8	3	Patch	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	No
BS1	Corner H	R8	4	Dipole	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	No
BS1	Omni	R9	3	Patch	41.4	31.4	42.4	27.5	27.5	25.1	33.7	36.1	33.7	34.9	33.4	Yes
BS1	Corner V	R9	4	Dipole	52.5	37.6	40.0	51.4	38.8	43.9	41.2	46.3	50.2	40.0	44.2	yes
BS1	Corner H	R9	3	Patch	42.433.7	31.4	32.5	40.0	34.9	29.8	33.7	31.4	34.9	40.0	34.3	Yes (10 sec)
BS1	Omni	R9	4	Dipole	42.4	51.4	61.2	50.2	43.9	46.3	51.4	56.1	53.7	47.5	50.4	Yes
BS1	Corner V	R9	3	Patch	42.4	53.7	45.1	51.4	48.6	45.1	43.9	48.6	51.4	43.9	47.4	Yes
BS1	Corner H	R9	4	Dipole	58.8	53.7	56.1	53.7	45.1	40.0	52.5	57.6	43.9	53.7	51.5	Yes (10sec)
BS1	Omni	R10	3	Patch	27.5	26.3	26.3	27.5	27.5	28.6	26.3	26.3	26.3	22.4	26.5	Yes
BS1	Corner V	R10	4	Dipole	42.4	38.8	37.6	38.8	40.0	29.8	47.5	33.7	38.8	33.7	38.1	Yes
BS1	Corner H	R10	3	Patch	29.8	21.2	27.5	13.7	31.4	28.6	31.4	26.3	31.4	26.3	26.8	No
BS1	Omni	R10	4	Dipole	53.7	52.5	48.6	42.4	45.1	42.4	51.4	45.1	48.6	52.5	48.2	Yes
BS1	Corner V	R10	3	Patch	36.1	41.2	33.7	36.1	32.5	28.6	38.8	36.1	33.7	31.4	34.8	Yes (9 sec)
BS1	Corner H	R10	4	Dipole	43.9	40.0	43.9	43.9	41.2	38.8	37.6	46.3	47.5	40.0	42.3	Yes (9 sec)

Experimental data acquired near DRDC Valcartier (R6 to R10)

Annex C: Experimental data acquired at CFB Valcartier (champ de tir)

Remote				Base Station		Signal Strength										Average	Note
Distance	**UTM Location (T19)**		**Antenna**	**Location**	**Antenna**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**		**Image**
(meter)	**North**	**East**				**(%)**	**(%)**	**(%)**	**(%)**	**(%)**	**(%)**	**(%)**	**(%)**	**(%)**	**(%)**	**(%)**	**(Y/N)**
0	5198585	307301	Patch	BS4	Whip	81.2	80.0	74.9	80.0	78.8	73.7	82.4	72.1	77.6	81.2	**78.2**	Yes
0	5198585	307301	Dipole	BS4	Whip	90.2	82.4	90.2	82.4	92.4	90.2	90.2	85.1	83.9	82.4	**86.9**	Yes
100	5198697	307297	Patch	BS4	Whip	42.4	38.8	36.1	36.1	41.2	40.2	37.6	33.7	36.1	33.7	**37.6**	Yes
100	5198697	307297	Dipole	BS4	Whip	62.4	76.1	62.4	77.6	72.5	62.4	72.5	73.7	67.5	62.4	**69.0**	Yes
200	5198791	307293	Patch	BS4	Whip	38.8	31.4	41.2	27.5	34.9	37.6	36.1	28.6	36.1	37.6	**35.0**	Yes
200	5198791	307293	Dipole	BS4	Whip	71.4	72.5	61.2	73.7	71.4	66.3	72.5	73.7	61.2	67.5	**69.1**	Yes
300	5198888	307289	Patch	BS4	Whip	28.6	33.7	20.0	31.4	33.7	31.4	27.5	27.5	28.6	22.4	**28.5**	Yes
300	5198888	307289	Dipole	BS4	Whip	57.6	58.0	54.9	58.8	56.1	54.9	56.1	57.6	56.1	60.0	**57.0**	Yes
400	5198992	307295	Patch	BS4	Whip	28.6	20.0	25.1	29.8	32.5	26.3	29.8	28.6	23.6	28.6	**27.3**	Yes
400	5198992	307295	Dipole	BS4	Whip	54.9	52.5	51.4	52.5	53.7	52.5	56.1	53.7	51.4	52.4	**53.1**	Yes
500	5199094	307272	Patch	BS4	Whip	25.1	28.6	26.3	22.4	23.9	25.1	25.1	20.0	22.4	23.9	**24.3**	Yes
500	5199094	307272	Dipole	BS4	Whip	48.6	48.6	42.4	40.0	37.6	37.6	52.5	50.2	52.5	53.7	**46.4**	Yes
600	5199194	307269	Patch	BS4	Whip	26.3	16.1	18.8	20.0	21.2	22.4	23.9	25.1	26.3	20.0	**22.0**	Yes
600	5199194	307269	Dipole	BS4	Whip	37.8	43.9	51.4	36.1	38.8	34.9	43.9	41.2	45.1	33.7	**40.7**	Yes
700	5199194	307260	Patch	BS4	Whip	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	**NA**	NA
700	5199194	307260	Dipole	BS4	Whip	50.2	46.3	48.6	48.6	50.2	48.6	51.4	50.2	48.6	47.5	**49.0**	Yes
800	5199396	307265	Patch	BS4	Whip	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	**NA**	No
800	5199396	307265	Dipole	BS4	Whip	51.4	43.9	41.2	48.6	34.9	41.2	47.5	41.2	46.3	42.4	**43.9**	Yes
900	5199491	307260	Patch	BS4	Whip	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	**NA**	NA
900	5199491	307260	Dipole	BS4	Whip	40.0	45.1	45.1	43.9	45.1	43.9	41.2	41.2	43.9	41.2	**43.1**	Yes
1000	5199592	307266	Patch	BS4	Whip	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	**NA**	NA
1000	5199592	307266	Dipole	BS4	Whip	38.8	37.6	36.1	27.5	38.8	31.4	36.1	32.5	37.6	34.9	**35.1**	Yes Slow
1100	5199683	307262	Patch	BS4	Whip	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	**NA**	NA
1100	5199683	307262	Dipole	BS4	Whip	38.8	34.9	36.1	34.9	33.7	36.1	33.7	32.5	34.9	36.9	**35.3**	Yes Normal
------	**------**	**------**	**------**	**------**	**------**	**------**	**------**	**------**	**------**	**------**	**------**	**------**	**------**	**------**	**------**	**------**	**------**
1700	5200289	307227	Dipole	BS4	Whip	33.7	31.4	36.1	31.4	32.4	33.7	32.5	33.7	32.5	33.7	**33.1**	Yes Slow

Set of data acquired at CFB Valcartier (champ de tir)

List of symbols/abbreviations/acronyms/initialisms

AMIGO	Autonomous Microsystems for Ground Observation
ARQ	Automatic Repeat Request
CF	Canadian Forces
CFB	Canadian Forces Base
CMOS	Complimentary Metal Oxide Semiconductor
CSE	Communications Security Establishment
DRDC-V	Defence Research and Development Canada - Valcartier
GPS	Global Positioning System
GUI	Graphic User Interface
HEX	Hexadecimal
IEEE	Institute of Electrical and Electronics Engineers
LAN	Local Area Network
LOS	Line Of Sight
LPD/LPI	Low Probability of Detection / Low Probability of Interception
NLOS	Non Line Of Sight
RDDC	Recherche et développement pour la défense Canada
RF	Radio Frequency
SAOON	Surveillance, d'Acquisition d'Objectifs et d'Observation Nocturne
STANO	Surveillance Target Acquisition Night Observation
UART	Universal Asynchronous Receiver and Transmitter
UTM	Universal Transverse Mercator

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The objective of project AMIGO (Autonomous MIcrosystems for Ground Observation) is to develop a proof-of-concept, low cost, compact unattended ground sensor suite that can provide real time situational awareness for the CF from remote locations. Two of the major components in AMIGO are the RF transceiver and antennas for wireless communication that must provide reliable connectivity between the base station and each remote unit in any battlefield conditions. The transmission scheme should also be low probability of detection and interception (LPD/LPI). After a vigorous selection process, the RF transceiver WIT2410 was chosen for this R&D work.

The WIT2410 (Wireless Industrial Transceiver) from Cirronet can provide wireless connectivity in point-to-point or multi-point applications. The frequency hopping spread spectrum technology of the WIT2410 ensures maximum noise resistance, multi-path fading immunity, robustness in presence of interfering signals, and LPD and LPI. In this work, different types of antenna and antenna configuration were tested with the transceivers at various locations at DRDC Valcartier. The RF signal strengths were recorded and compared. With this information, one can determine the WIT2410 limitation, reliability, and achievable range in different settings.

With the transceiver set at 100mW RF output power, the best signal strength-to-distance was obtained by using the Cirronet 2 dB dipole antenna (RWA249R) for the remote sensors located both indoor and outdoor at ground level and the Cirronet 9 dB omnidirectional antenna (OMNI249) for the base station located at an elevated position. With line-of-sight (LOS), reliable transmission between the remote sensor and the base station was obtained up to 1500 m. With non-line-of-sight (NLOS) scenarios varying from obstructions of a few trees to multiple buildings, the range of reliable transmission was averaged at about 450 m. When the remote sensor was located inside a building, the signal strength was reduced by an average of 15%.

According to this result and understanding the transceiver limitation, one could deploy a wireless network sensor suite efficiently and reliably in opening field and urban operations

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IEEE 802.11 Protocol, RF Tranceiver, Wireless Industrial Transceiver, Wireless Data Transmission, Spread Spectrum, Unattended Ground Sensors, Antenna

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