WiMAX Experimentation and Verification in Field in Italy

Jonathan Buschmann, Francesco Vallone, Paris Dettorre, Andrea Valle, Gianluca Allegrezza
Ericsson Telecomunicazioni SpA
Rome, Italy

ABSTRACT

Under the auspices of the Italian Communications Ministry, in a trial program directed by the UGO Bordoni Foundation, Ericsson performed extensive field tests to verify and measure the performance of IEEE 802.16-2004 compliant equipment in the 3.5 GHz band. The trial was strictly technological in nature, with the goals of validating the claimed technical characteristics of this technology and determining the behavior of a point-to-multipoint technology in this frequency band. The experimentation was carried out with equipment from Airspan, a global partner of Ericsson. Measurements were done both at the radio bearer layer and the packet data layer. At the radio layer coverage and propagation were measured and characterized. Studies are under way using these results to develop a propagation model of the 802.16-2004 signal in the 3.5 GHz band. In addition, inter-cell interference was measured. At the packet layer, throughput, packet loss, and jitter were measured under varying field conditions, including various types of terrain and differing levels of clutter. Standard service functionality and performance were verified and measured with particular attention to the QoS support defined in the 802.16-2004 standard.

Keywords
WiMAX, 802.16-2004, radio coverage, throughput, propagation, QoS

1. TRIAL BACKGROUND

In June 2004 the IEEE approved the standard entitled “Air Interface for Fixed Broadband Wireless Access Systems”; commonly referred to as 802.16-2004 [1]. Equipment based on this standard became readily available in the second half of 2005, at which time the certification process in the industry forum, “Worldwide Interoperability for Microwave Access” (WiMAX), also began. The equipment used in these tests has been WiMAX certified.

The frequency band selected by the WiMAX Forum for licensed operation of 802.16-2004 equipment is the 3.5 GHz (3.4-3.6GHz) band. In Italy this frequency band is currently allocated to the Ministry of Defense. The UGO Bordoni Foundation, a government think tank, together with the Ministry of Communications and the Ministry of Defense, decided to organize an extended technological field trial of 802.16-2004 equipment with the aim of demonstrating the real performance and capabilities of this new technology under realistic deployment scenarios. A limited number of available frequency channels in limited areas of Italy were identified by the Military for which temporarily use was granted for the trial period. EIRP was also limited to 36dBm.

This article reports results obtained first separately, and later jointly, from Ericsson and the former Marconi - now part of Ericsson - which have participated under the auspices of the trial program.

2. EXPERIMENTAL SETUP

Equipment was setup in several regions of Italy: Rome, Sicily, and the Piedmont region, enabling us to test this technology under terrain and clutter conditions that vary from urban to sub-urban to rural environments. Equipment was professionally installed, with an indoor unit containing both the RF and baseband units, and mast mounted outdoor antennas for the Base Station.

The Base Station (BS), Network Management System (NMS), and Customer Premises Equipment (CPE) employed were supplied by Ericsson’s worldwide partner, Airspan Networks. The Airspan MacroMAX BS and EasyST and ProST CPEs are FDD apparatuses operating in the 3.4-3.6GHz band using 3.5MHz channeling. One MacroMAX unit supports one channel and connects in RF using traditional 7/8“ feeders to two outdoor antennas for utilizing Maximal-ratio Combining (MRC) diversity. 60° directional with 10° elevation and 16 dBi gain, and omni-directional antennas were used alternatively in the tests.

The BS and CPEs have 100Mbit Ethernet network interfaces. The EasyST are plug-and-play indoor CPEs utilizing either an external window-mounted antenna, or an integrated 4 sector automatically-switched 6 dBi antenna. The ProST is a professionally installed external unit with a high gain (17 dBi) antenna. The CPEs connect either to a single computer or via a hub or switch to a Local Area Network. The MacroMAX and CPEs both behave as transparent Layer 2 switches. The NMS runs on a PC in the “service network” and communicates in band via the BS network interface. It provides management, alarm monitoring, and provisioning functions, in addition to SW upgrade support. Another PC in the service network was used for logging, tracing, and testing. An “Application Farm” contains several servers for testing different applications. The following diagram illustrates the typical site setup:

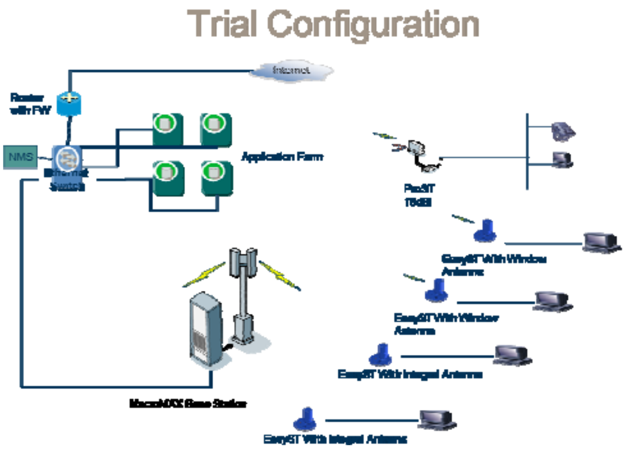

Figure 1: Trial Setup

Before initiating the field tests a series of lab tests were performed on the WiMAX equipment using an Agilent Vector Analyzer / WiMAX Signal Analyzer Tool for IEEE 802.16-2004. In this way the output power and conformance of the BS and CPEs to the 802.16-2004 standard were verified.

In the next three sections we describe the results of three groups of tests performed:

- Section 3 discusses the radio coverage drive tests to map the WiMAX radio coverage and evaluate the propagation effects of the radio signal at 3.5GHz

- Section 4 provides the results of the tests to determine the throughput and other measures of performance at the data packet level

- Section 5 discusses the tests and results verifying the service functionality offered by the 802.16-2004 protocol

3. RADIO COVERAGE AND PROPAGATION

The first field tests were performed to better understand the propagation characteristics of the radio signal in the 3.5GHz band and to map the coverage in the radio cell. These results also enabled us to better interpret the data performance tests performed later.

A specially equipped test van, formerly used for radio coverage tests for UMTS in the 2.1GHz band, was used for these measurements. The van contains a Rohde & Schwarz Signal Analyzer and software with an upgraded receiver which now operates up to 7 GHz, and a synchronized geo-referential receiver and software for precise radio coverage mapping. The signal was sampled according to the "LEE Criterion" [2] in time and space. Below is an example of such a drive test in an urban environment (unfortunately much information is lost in the conversion from color to grayscale.)

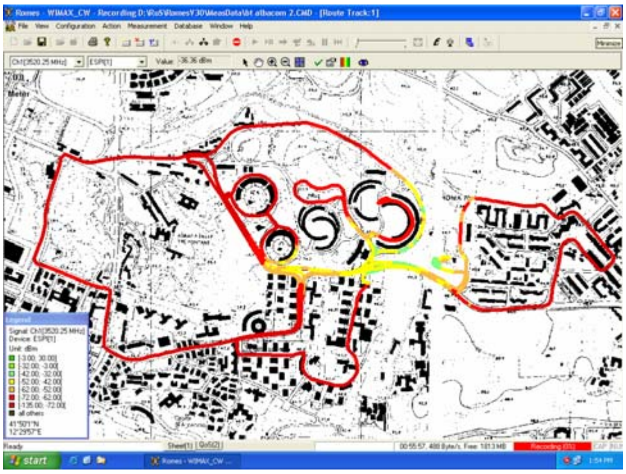

Figure 2: Drive Test

The radio signal in the 3.5GHz band propagated well in Line-Of-Sight (LOS) and Near LOS conditions. Even at the limited power output allowed, about 4 watts, a usable radio signal reached several kilometers. Corner effects (signal fall off when entering a shadowed area) near the BS were abrupt, as can be seen by the rapid transitions in signal strength in Figure 2. Under such conditions reflected signals are an important component, and techniques such as diversity and intelligent antennas become critical elements for offering a successful service.

Work is currently in progress utilizing the radio coverage data to develop an 802.16-2004 propagation model.

4. PERFORMANCE AND THROUGHPUT

The major part of the experimentation effort was dedicated to measuring the performance of the WiMAX equipment under varying conditions, varying settings of critical parameters, and with the two different types of CPEs. IP packet throughput, packet loss, latency, and jitter were measured. In addition, for each set of measurements the conditions of the test were noted: power received, SNR, modulation used, and distance from the BS and LOS conditions.

The typical measurement setup consisted of a portable PC connected to a CPE, communicating with a PC in the Service Network connected to the BS. For outdoor measurements the test van was again put into service equipped with an EasyST and external antenna.

For measuring latency the common *Ping* command was used. For measuring throughput, jitter, and packet loss, the open source software tool *Iperf* [3] was used. Iperf is an extremely flexible tool allowing the generation of TCP or UDP traffic at specific traffic rates together with the tuning of various parameters. The BS and CPE furnish management interfaces for reporting signal strength, SNR, and the current modulation being used.

Tests were carried out indoor up to about 500m, and outdoor both in NLOS conditions up to 3Km and in LOS conditions up to about 7 Km. The figure below illustrates some of the measurements made in an around the Ericsson campus site in Rome – a suburban area.

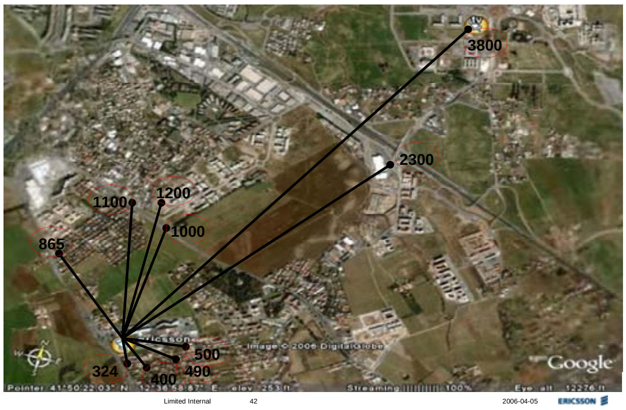

Figure 3: Rome Site (distances in meters)

The next figure shows the setup in Sicily around Palermo – a rural area.

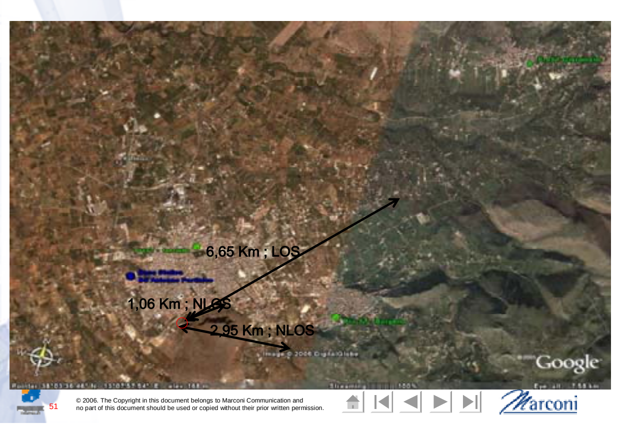

Figure 4: Sicily Site

In this location outdoor CPEs with directional high gain antennas were used in LOS and near-LOS conditions.

Throughput

802.16-2004 uses a dynamic modulation scheme and FEC coding (although via the NMS the modulation for a specific CPE may be fixed.) These modulations are (fractions indicate FEC coding) 64QAM ¾, 64QAM 2/3, 16QAM ¾, 16QAM ½, QPSK ¾, QPSK ½, BPSK ½.

Peak maximum net throughput in the downlink with a modulation of 64QAM ¾ reached 9.8 Mbit/s at a distance of 20m in LOS conditions with the ProST CPE. Uplink throughput is currently limited to at least half the theoretical limit due to the CPE chipset design (which is half-duplex) and scheduler tradeoff connected with this limit in the CPE. In fact, a maximum uplink throughput of 4.5 Mbit/s was measured under similar conditions. Efforts are underway, however, via a more intelligent scheduler in the CPE, to overcome this limitation.

The following graph demonstrates the downlink throughput under NLOS conditions measured as a function of distance from the BS in the main lobe of a 60° antenna corresponding to the setup seen in Figure 3 and using an EasyST CPE:

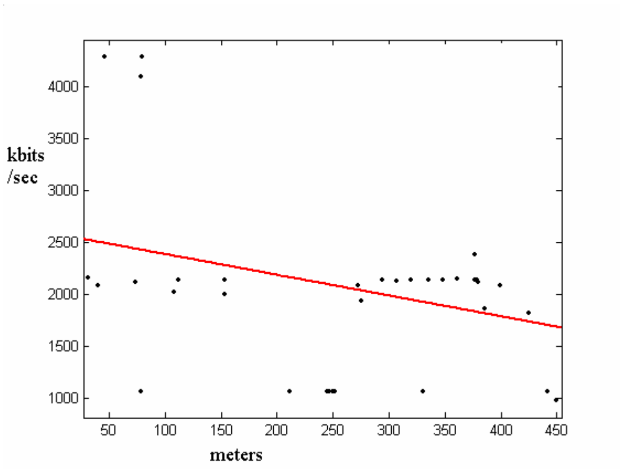

Figure 5: NLOS throughput (sub-urban area)

The clutter and fading effects in a sub-urban area are very evident in the large variation of throughput at similar distances from the BS.

The measurements in NLOS corresponding to the rural area depicted in Figure 4 are much more predictable, as seen below:

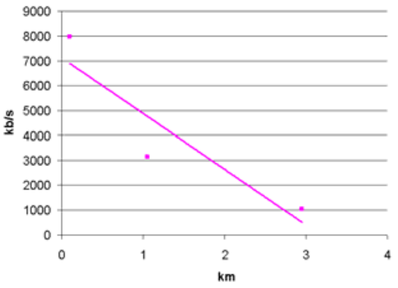

Figure 6: NLOS throughput (rural area)

Once again these results were obtained using the EasyST CPE with an external antenna. The next figure graphs the throughput under LOS, or near LOS, conditions in the sub-urban area:

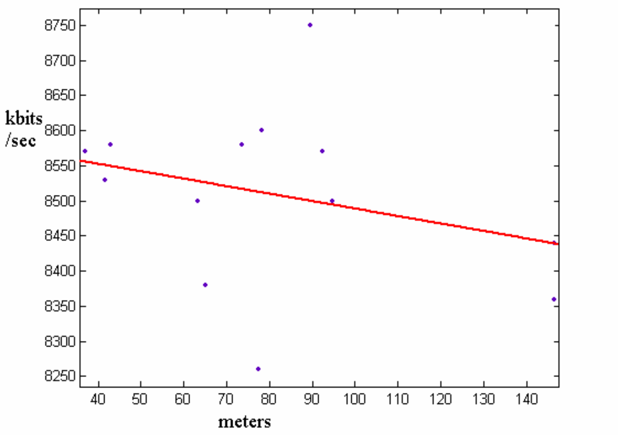

Figure 7: (Near) LOS throughput (sub-urban area)

Here, under (near) LOS conditions, throughput remains in a range ±250 kbits/sec.

In addition, in the rural setup seen in Figure 4 under LOS conditions and using an outdoor CPE (ProST), a throughput of 8 Mbits/s at a distance of over 6 Km was achieved.

Latency and Jitter

The one-way system latency was consistently around 35 ms. As we will see later, though, using rigid uplink schedulers, latency can be reduced. Jitter varied according to conditions and modulation. When using higher modulations or under severe NLOS conditions (much varying reflected signal) jitter was around 6 or 7 ms. Under more stable conditions it was consistently under 3 ms.

Multiple CPEs

Tests were also performed with up to 5 CPEs connected and communicating with the BS simultaneously. Total available bandwidth (currently about 10 Mbit/s) was seen to be utilized globally. Without any service profiling (discussed later), i.e., just simple best effort provisioning on all CPEs, bandwidth was fairly and uniformly proportioned among all the CPEs.

Inter-Cell Interference

In a first series of interference tests, two adjacent 60° cells (generated by two separate BS) were put on air on adjacent 3.5MHz frequency channels to determine interference effects. Two CPEs were put at a close distance (about 20m) from the BS antennas and between the two cells in such a way that they received equally power from the 2 BS antennas. The two CPEs were configured to connect one each to the two separate BS.

When the CPEs were placed only 1 meter apart (an unlikely deployment) and traffic passed on both links a significant interference was noticed – a reduction of throughput of about 40%. Instead, when the two CPEs were separated by only about 3 meters this interference effect essentially disappeared. The results of this latter test can be seen in the figure below.

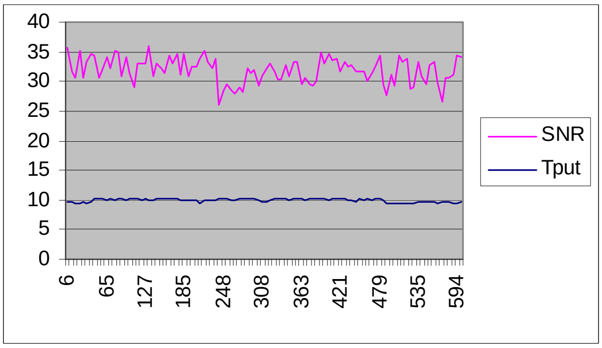

Figure 8: Interference between adjacent cells

In Figure 8 a 10 Mbit/s interfering traffic was begun at time 260 sec and which lasted for 120 sec, and a 1 Mbit/s interfering traffic was generated at time 440 sec which lasted for 60 sec.

A second series of tests were performed with both BS using the same frequency channel. Measurements of throughput were carried out on one CPE connected to one of the BS while varying the power of the second "interfering" BS. When the power of the second BS was equivalent to the first a significant interference was measured – about a 50% reduction in throughput. When the interfering power was reduced by 20 dBm instead the interference was found to be negligible. These results can be seen in Figure 9 below, where a traffic of 5 Mbit/s was sent downlink to the measuring CPE.

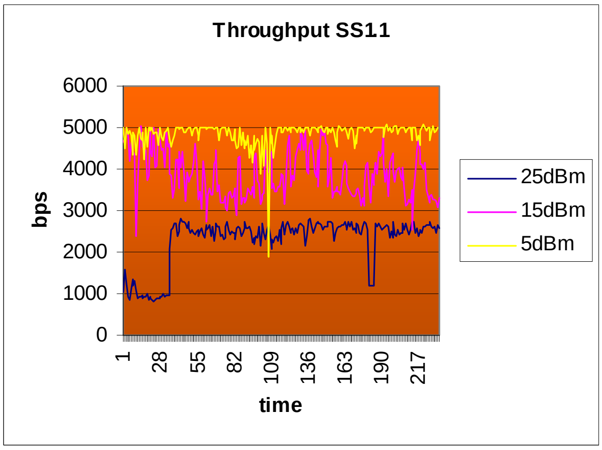

Figure 9: Same frequency interference

5. SERVICE FUNCTIONALITY AND SERVICE PERFORMANCE

The 802.16 standards are the first from the IEEE 802 family (which includes wired Ethernet and WiFi) that do not use the Ethernet MAC, which is based on a CSMA/CD (Carrier Sense Multiple Access with Collision Detection) scheme. Instead, the 802.16 group defined a completely new MAC: a slotted TDMA protocol with intelligent scheduling (not contention based) and with a grant/request protocol (QoS hook). This new MAC permits WiMAX to carry services on the radio link with guarantees of Quality of Service (QoS).

Packets destined for transmission via the radio interface (at the CPE, or at the BS destined for a CPE), are treated according to the Service Product (SP) provisioning defined in the NMS. First, each packet is compared to a series of Packet Classifiers defined in the SP. These classifier rules can identify packets according to either Layer 2 rules (e.g., MAC address) or according to Layer 3 rules (IP address, IP Port, or Diffserv marking). The order in which each rule is tried on an incoming packet is determined by a Rule Priority: this allows more restrictive rules, like IP port rules, to be applied over a more liberal rule, which for instance passes all IP traffic. On the basis of this classification the packets are assigned to pre-defined Service Classes (SC). Each SC is also assigned a Traffic Priority which is used by the Packet Scheduler of the BS or CPE to prioritize the transmission of the packets. In addition to this priority the SC can contain a series of QoS constraints and guarantees, which include maximum and minimum information rate, maximum jitter and latency, and maximum traffic burst. In the case of traffic scheduled at the CPE, i.e. destined for the uplink, the type of scheduler needs also to be specified. The scheduler types available are Best Effort (BE), Real-Time Polling (rtPS), Non-Real Time polling (nrtPS), or Unsolicited Grant Service (UGS). For the latter types the polling period also needs to be specified. The BS, instead, schedules traffic for all provisioned CPEs in the most efficient manner possible according to Service Priorities and the QoS constraints configured for each SC.

The 802.16-2004 standard permits the specification of a large number of parameters affecting service quality, and consequently a vast number of combinations of these parameters is possible. Also, in addition to the QoS parameters specified above, there are also physical layer and MAC parameters, such as frame length and cyclic prefix, which have an impact on service quality and system throughput. As such, our tests consisted of first verifying the predicted behavior of different parameters; for instance, reducing the frame length reduces latency and jitter, but decreases throughput. Then service simulation tests were begun to determine the overall effects on service of various system configurations. What quickly became apparent was that care was needed in the selection of combinations of parameters. The configuration of UGS in particular requires special attention to the combination of polling period, latency, and frame length. Consequently, in order to carry out a more reasonable number of tests, first, combinations of settings that would be typically used for offering certain services were identified, and then the performance characteristics of these settings were measured.

The service settings used were typical of:

1. a general internet data access;
2. a Voice over IP (VoIP) service;
3. a video streaming service;
4. an interactive gaming service;

and combinations of these.

Service 1 uses a best effort scheduler in the uplink, and was the default used for all the standard performance and throughput measurements discussed in Section 4. Using this scheduler, however, various maximum throughput rates were applied for various CPEs to verify the scheduler's ability to respect these guarantees. Also, in the presence of several CPEs transmitting or receiving traffic simultaneously a minimum traffic rate was configured for one CPE to verify this guarantee. All of these guarantees were in fact verified.

For Service type 2, two different schedulers on the UL were used for the VoIP traffic: UGS and rtPS. Packets belonging to the VoIP class were classified according to IP port destination. A best effort traffic class was also configured to provide background traffic in order to test the guarantees and performance of the schedulers. So far these tests were done only with a limited number of CPEs in service; future tests will aim at stressing further the system capacity limits, and we will be able to confront our measurements with simulations done – for instance those found in [4].

The UGS scheduler furnishes exemplary latency and jitter performance: latency is reduced by about 50% and jitter is almost negligible. The greatest limitation with UGS is that it statically dedicates an amount of UL bandwidth, which consequently is unavailable for other services, including services on other CPEs, even if traffic is not at that moment present on the service. It is akin to a reserved circuit. This effect was in fact clearly measured in our tests when passing traffic on other service classes. An alternative strategy, which is currently being studied, is to implement mechanisms which dynamically provision and tear down UGS connections when needed (for instance when traffic on a certain port is seen, or absent for a certain time interval, at the CPE or BS). rtPS, which offered similar performance (although its performance under a fully stressed system remains to be tested), was found to be much more flexible – allowing bandwidth to be used for other data flows when not needed for the service dedicated to it.

Service of type 3, a video streaming service, was provisioned using multicast and a dedicated VLAN. A set of CPEs were guaranteed bandwidth by being assigned to a certain VLAN. Traffic on a certain multicast address was restricted at the BS to this VLAN and it was verified that the correct CPEs received traffic.

Work on Service type 4 is still under progress to determine the most efficient bandwidth reservation and scheduling mechanisms that are applicable.

6. CONCLUSIONS

An extensive range of tests performed both at the radio layer and packet data layer confirmed in large part the performance promised by WiMAX. Being a technology originally aimed at LOS and near LOS service with high modulation and the possibility of using fixed high gain directional antennas, the most impressive performance of WiMAX is seen under just these sorts of conditions. In indoor deployments and under high clutter conditions NLOS performance necessarily suffers, with rapid falloff when leaving conditions of BS visibility; however, the benefits of using licensed spectrum and high power BS should give WiMAX strong advantages with respect to current solutions providing similar service, such as WiFi and Hiperlan.

The efficient new MAC layer and the service guarantees offered by the standard make WiMAX a very attractive solution for "last mile" data access; although, as a young and still growing standard, time is needed to consolidate and rationalize the enormous optionality WiMAX has to offer to provide simple dependable services.

7. REFERENCES

---

[1] IEEE 802.16-2004: "IEEE Standard for Local and Metropolitan Area Networks – Part 16: Air Interface for Fixed Broadband Wireless Access Systems"
[2] Lee, W.C.Y., "Estimate of Local Average Power of a Mobile Radio Signal", IEEE Trans. Veh. Tech., February 1985
[3] "NLANR/DAST: Iperf 1.7.0 - The TCP/UDP Bandwidth Measurement Tool" http://dast.nlanr.net/Projects/Iperf/
[4] Cicconetti, Claudio, et al, "Quality of Service Support in IEEE 802.16 Networks", IEEE Network, March/April 2006