Research and Development
on the Broadband Communication System for Airplane using Millimeter-wavelength band

December 4th, 2008

Mikio Suzuki, Hiroyuki Tsuji, Derek Gray, Takayuki Morisaki

National Institute of Information and Communications Technology
## Back Ground & Trends...

<table>
<thead>
<tr>
<th>Date</th>
<th>Test Description</th>
<th>Location</th>
<th>Distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>June-July, 2002</td>
<td>3G Mobile &amp; Digital Broadcasting Relay Test using Path Finder Plus</td>
<td>Kauai Is.</td>
<td>20km</td>
</tr>
<tr>
<td>Oct, 2002</td>
<td>Digital Broadcasting Test using Gulfstream II</td>
<td>Hokkaido</td>
<td>12km</td>
</tr>
<tr>
<td>Nov, 2002</td>
<td>Broadband Access Test (28/31GHZ &amp; 47/48GHz) using Helicopter</td>
<td>YRP</td>
<td>3km</td>
</tr>
<tr>
<td>Nov, 2004</td>
<td>Broadcasting for Wide-area, Mobile Localization &amp; Optical Link Test using Airship</td>
<td>Hokkaido</td>
<td>4km</td>
</tr>
</tbody>
</table>

Results should be applied to next phase R&D...

"Ubiquitous & Universal Aeronautic Communications System" (tentative) as New Information & Communications Infrastructure
Post HAPS Project #1
“High-speed IP Communication System using Airship”
Innovative Wireless Communications System Concept

- Satellite
- Manned/unmanned airship
- Intelligent UAV
- Adhoc wireless network for disasters
- Emergency access link post-disasters and temporary events
- HDTV video reception and broadband downlink
- Sensor information
- Safety monitoring and broadband link for trains
- Safety monitoring and broadband link for ships
- Emergency video transmission for wide area
- Safety support for elderly/children

Monitoring and warning of natural disasters and criminal activities
High-res search for missing person
Safety monitoring and broadband link for ships
Safety monitoring and broadband link for trains
Emergency video transmission for wide area
Safety support for elderly/children
Conceptual outline of High-speed IP Communication test using Airship

Digital beam forming antenna with 100 elements (RX)

Zeppelin NT

Miniature reflector drive antenna (TX)

Payload: total 290 kg

Variable reflector

31 GHz

Millimeter band multibeam

50Mbps/beam transmission rate

28 GHz

IP access link with portable terminals
- HDTV Transmission
- Internet access with PDA, PC
- VoIP Communication

Flexible deployment in emergency situation

Adaptive/scanning cells
Mission equipment and radio station

Portable ground station
- Reflector drive antenna
- Power supply
- Monitor and control

Aerial Base station (airship on-board)
- DBF antenna
- DBF signal processor
- Modulator/demodulator
- Control for Reflector drive antenna

Ground mobile station (NiCT vehicle on-board)
- Antenna TX & RX
- Mobile test car (NiCT vehicle)
Zeppelin-NT Airship

Feature
- Largest size in the world
- Only 3 ships in the world
- Used helium gas
- High mobility
- Low noise in cabin
- Low environmental load

Merit
- Low noise → Good for rescue
- Low vibration → Good for equipments
- Station keeping capability
- Flight in safety

Specification

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td>75 m</td>
</tr>
<tr>
<td>Width</td>
<td>19.5 m</td>
</tr>
<tr>
<td>Height</td>
<td>17.4 m</td>
</tr>
<tr>
<td>Capacity</td>
<td>8,225 m³</td>
</tr>
<tr>
<td>Passenger</td>
<td>14</td>
</tr>
<tr>
<td>Cabin length</td>
<td>10.7 m</td>
</tr>
<tr>
<td>Max weight</td>
<td>8,040 kg</td>
</tr>
<tr>
<td>Max payload</td>
<td>1,900 kg</td>
</tr>
<tr>
<td>Max speed</td>
<td>125 km/h</td>
</tr>
<tr>
<td>Cruising range</td>
<td>900 km</td>
</tr>
<tr>
<td>Max altitude</td>
<td>2,600 m</td>
</tr>
<tr>
<td>Cruising time</td>
<td>24 hours</td>
</tr>
</tbody>
</table>

Cockpit
Cabin
Cruising
Zeppelin-NT Airship

Base station near by HONDA Airport
Loading equipments to Airship

captive airship
floating condition
Honey cum construction
maintenance aperture
Radome for antennas
loaded in cabin

NiCT
On-board antennas

- **31GHz**
  - 100 elements DBF antenna

- **31/28GHz**
  - Waveguide antenna

- **28GHz**
  - Mechanical drive antenna

Other equipments... CCD camera, MPEG encoder/decoder, GPS gyro, HD camera, RF/IF modulator/demodulator, PC
## Digital beam forming antenna

<table>
<thead>
<tr>
<th>Item</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>General</strong></td>
<td></td>
</tr>
<tr>
<td>input frequency</td>
<td>31.0375GHz</td>
</tr>
<tr>
<td>IF frequency</td>
<td>245.5MHz</td>
</tr>
<tr>
<td>band width</td>
<td>34MHz</td>
</tr>
<tr>
<td>antenna element</td>
<td>100 (10 x 10)</td>
</tr>
<tr>
<td>antenna gain</td>
<td>16.4dBi</td>
</tr>
<tr>
<td>beam width</td>
<td>10°</td>
</tr>
<tr>
<td>G/T</td>
<td>-15.5dB/K</td>
</tr>
<tr>
<td>fixed beam</td>
<td>81 beam</td>
</tr>
<tr>
<td>scanning beam</td>
<td>2 beam</td>
</tr>
<tr>
<td>detector</td>
<td>digital IF detector</td>
</tr>
<tr>
<td><strong>Antenna element</strong></td>
<td></td>
</tr>
<tr>
<td>antenna type</td>
<td>dipole</td>
</tr>
<tr>
<td>gain</td>
<td>0dBi</td>
</tr>
<tr>
<td>array</td>
<td>square array</td>
</tr>
<tr>
<td>array space</td>
<td>5.08mm</td>
</tr>
<tr>
<td><strong>RX module</strong></td>
<td></td>
</tr>
<tr>
<td>NF</td>
<td>3.6dB</td>
</tr>
<tr>
<td>gain</td>
<td>70±1dB</td>
</tr>
<tr>
<td>power consumption</td>
<td>240W</td>
</tr>
<tr>
<td><strong>Digital signal processor</strong></td>
<td></td>
</tr>
<tr>
<td>ADC sampling frequency</td>
<td>91.2MHz</td>
</tr>
<tr>
<td>ADC accuracy</td>
<td>12Bit</td>
</tr>
<tr>
<td>weight</td>
<td>Taylor or uniform</td>
</tr>
<tr>
<td>power consumption</td>
<td>600W</td>
</tr>
</tbody>
</table>

## Mechanical drive antenna

<table>
<thead>
<tr>
<th>Item</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>General</strong></td>
<td></td>
</tr>
<tr>
<td>input frequency</td>
<td>28.3075GHz</td>
</tr>
<tr>
<td>IF frequency</td>
<td>245.5MHz</td>
</tr>
<tr>
<td>band width</td>
<td>34MHz</td>
</tr>
<tr>
<td>antenna gain</td>
<td>25.0dBi</td>
</tr>
<tr>
<td>EIRP</td>
<td>8dBW</td>
</tr>
<tr>
<td>beam width</td>
<td>8°</td>
</tr>
<tr>
<td>detector</td>
<td>digital IF detector</td>
</tr>
<tr>
<td>antenna mount</td>
<td>XY mount</td>
</tr>
<tr>
<td>motor &amp; control</td>
<td>brushless DC motor/feedback control</td>
</tr>
<tr>
<td>pointing accuracy</td>
<td>1db</td>
</tr>
<tr>
<td>scanning angle</td>
<td>45° in mechanical 30° in electrical</td>
</tr>
<tr>
<td><strong>Antenna element</strong></td>
<td></td>
</tr>
<tr>
<td>antenna sysytem</td>
<td>colgate horn antenna with 2 reflectors</td>
</tr>
<tr>
<td>TX module</td>
<td></td>
</tr>
<tr>
<td>TX power</td>
<td>23dbm</td>
</tr>
<tr>
<td>Power consumption</td>
<td>6W</td>
</tr>
</tbody>
</table>
Ground mobile station

Ka band waveguide antenna

CCD camera

MPEG encoder/decoder, PC, GPS gyro, monitor

Carrier on roof

HD video camera

NiCT
Ground portable station

- Miniature mechanical drive antenna
- Controller
- Power supply
- PC for IP control
- Access point for wireless LAN
- IP mobile telephone
- HD Monitor
- Miniature mechanical drive antenna
Field test in Saitama prefecture ~public square~

Station keeping over AKIGASE Park

Portable ground station in AKIGASE Park

Mobile station

Portable ground station at the roof of city hall

( Jan.5th~9th, 2007 )
Field test in Saitama prefecture ~public square~

Mt. Fuji from Airship altitude 1,000m

OOMIYA athletic ground

Portable ground station

move along square area

mobile station

road in the park

( Jan.11th, 2007 )
Field test in Shibuya Tokyo ~ NHK Center ~

Station keeping over NHK Center in Shibuya, Tokyo

( Jan.10th, 2007 )

Drive around NHK Center in Shibuya

HD TV video transmission test

Portable station in parking lot of NHK Center

HD Camera controller

Roof-mounted HD Camera with azimuth/yaw mechanism
Test configuration

Base station (airship on-board)
Altitude 500-1,500m

100 elements digital beam forming antenna (RX)

reflector drive antenna (TX)

Global beam

Portable ground station

modem
Ether Interface

Wireless LAN router

HD video camera

monitoring the car

HD video camera

802.11

IP telephone

TV telephone

Internet

Multi-beam uplink

Mobile station
Data sample ~ DBF antenna tracking beam~

Ka band DBF antenna: flexible beam control, compensate airship rolling, multi beam (81 beams)
Ka band miniature mechanical drive antenna: broadband (300MHz), compact mechanism
Demonstration ~IP communication~

① measure throughput
② monitor remotely
③ VoIP
④ TV/IP telephone
⑤ HD video transmission

☆ 25Mbps transmission rate for HD video signal on two-way communication
☆ 50Mbps transmission rate on one way communication
Post HAPS Project #2
“Broadband Aero Hotspot System for Airplanes”
Many needs in the Airplane for Ubiquitous Environment

- Mobile phone using Satellite couldn’t be expected, CBB business withdrawal
- Increasing of traffic except voice (mail, web browsing, broadcasting, music, other entertainment)

Service Planning to use UHF band for Airplane world-wide

- Aircell planned to test the system using cellular phone frequency in USA
- Airbus intends to realize cellular phone in Airplane with Siemens in EU

Established the millimeter system technology, brush up needed

- Noting the system connecting airplane and ground in the world
- Suitable for broadband communication in line of sight environment

Expected to be used in another system

- Communication system on ships and trains under base station at high altitude
- Broadband data reduction system via airplane on the disaster
CBB (Connection by Boeing) withdrew the business

Antenna system for satellite communication (designed by Mitsubishi Elec.)

Operated 150 airplanes in the world since 2004
Closed in the end of 2006
AirCell said it is ready to launch a national air-to-ground in-flight network. The network would allow a traveler to connect a BlackBerry to the Internet using Wi-Fi. AirCell has signed a contract with American Airlines for a 15-plane trial.

- Base stations of cellular phone should be installed antennas with upward
- Built up cell in air by 800MHz band
- Airplane fly between cells by hand over
- Pico cells should be built up in cabin for networking
Concept of “Aero Hot Spot” in Japan

- Airplane should fly along the equipments such as VOR, DME
- Those are equipped in place of wide outlook

VOR: VHF Omnidirectional Range
DME: Distance Measuring Equipment
VOR/DME in Japan

DME: Distance Measuring equipment
UHF (960–1515MHz)

VOR: VHF Omni directional Radio range beacon
VHF (108–118MHz)

top of hill

on the building
VOR/DME in CHIBA Pref.

wide outlook place
VOR/DME in Ibaraki Pref.

DME fixed in the center of VOR
Conceptual System Configuration

Ground station for millimeter wave should be around VOR/DME
Broadband Aero Hotspot Configuration

- On-board relay / mobile router
- In cabin: 1~10Mbps / user
- On-board tracking antenna
- Millimeter band relay communication (50~100Mbps)
- Ground tracking antenna around existent DME/AOR
- Ground tracking antenna on building

- Network (Telephone, Cellular phone, Internet)
- 2nd, 3rd, 4th cellular phone
- PHS
- Wireless LAN
- IP telephone
- e-Mail
- Internet
- Receiving TV

Low cost, compact size
## Specification

<table>
<thead>
<tr>
<th>Service area</th>
<th>Specification</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>100km radius/airplane</td>
<td>100km~50km: 1Mbps</td>
</tr>
<tr>
<td></td>
<td>(Altitude: 10km)</td>
<td>50km~20km: 10Mbps</td>
</tr>
<tr>
<td></td>
<td></td>
<td>20km以下: 100Mbps</td>
</tr>
<tr>
<td>Transmission rate</td>
<td>100Mbps max</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(1Mbps ~ 100Mbps Valuable)</td>
<td></td>
</tr>
<tr>
<td>Communication</td>
<td>Full duplex communication</td>
<td></td>
</tr>
<tr>
<td>Frequency</td>
<td>43.5GHz ~ 47GHz</td>
<td>tentative plan</td>
</tr>
<tr>
<td></td>
<td>Up link: 43.65GHz ± 150MHz</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Down link: 46.85GHz ± 150MHz</td>
<td></td>
</tr>
</tbody>
</table>
Shift from microwave band to millimeter band is needed

- Expand the application of millimeter wavelength to mobile communications
- Airplane, Railway, Ships and Bus needs broadband communication tool
- In-cabin millimeter communication needed in worldwide
Collaboration on R&D
~ NICT and Mitsubishi Elec. Corp. ~

Aero broadband communication system
Access control, Search & Track technology
In-cabin wireless communication environment

NICT

High speed mobile network technology
Minimum data loss on handover
Control technology on optimum air route

Mitsubishi Electric Co.

Millimeter wavelength array antenna
Active phased array antenna
Beam steering technology

Mitsubishi Electric Co.

Some technical issues
Millimeter band ground antenna

Feature
- Mechanical tracking of flat reflector
  (light weight, low cost)
- Using lens antenna
  (small size)
- Mono pulse tracking
  (High resolution tracking)

Lens antenna
(1st trial production 2006)
(2nd trial production 2007)

4 elements lens antenna

1 element multimode lens antenna

Antenna gain: 40 dB
TX power: 36 dBm

use for telecommunication

use for search & tracking
Antenna pattern measured (43.5GHz)

- Frequency: 43.65GHz ~ 46.85GHz
- Antenna gain: >42dBi
- Beam width: >1.5°
- Side lobe level: <-25dB
Antenna pattern measured (47GHz)

Specification

- Frequency: 43.65GHz ~ 46.85GHz
- Antenna gain: >42dBi
- Beam width: >1.5°
- Side lobe level: <-25dB
**In cabin Electro-magnetic environment**

- Broad band communication in cabin
  - Wi-Fi wireless LAN
  - Millimeter band system
  - Femtocell system
- 2.4GHz for Wi-Fi wireless LAN were carried out by CBB, EU and ARIB
- Under consideration for near field transmission analysis in IEEE802 activity
- Done the simulation on electro–magnetic environment in various frequency (800MHz band, 2GHz band, 3GHz band, 10GHz band, 60GHz band)

In cabin model (YS-11)
In cabin Electro-magnetic environment

- results on simulation -

Millimeter band (60GHz)

Investigation under vertical dipole antenna on the roof

2GHz band (WCDMA femtocell)

- Femtocell output : 13.0dbm
- Minimum receiving level of cellular phone : -117.00dBm

☆ Same effect in shading between 3GHz and 60GHz
☆ Over 4m spacing for each antenna makes shading
☆ 3.5db variation for eleven seats

NiICT
Trial test in ground chamber at NICT

On-board access equipment, ground access equipment, on-board antenna and ground antenna were integrated in ground chamber on this February.

Successful results

100Mbps rate in millimeter wavelength band (Up Link: 46.85GHz, Down Link: 43.65GHz)
Transmission rate was 98.42Mbps using Smartbit

Transmission rate: 「Rx Frames × 1514」(byte) × 8bit/9.999953sec=98.42Mbps
IF signal spectrum observed (1500MHz) via RF signal transmitted (43.65GHz)
Demonstration test configuration

- Beam tracking
- APAA performance
- Handover
- Access control
## Summary of R&D milestone

<table>
<thead>
<tr>
<th>Year</th>
<th>Technical Survey &amp; Conceptual Design</th>
<th>Partial Trial-production</th>
<th>Partial Evaluation</th>
<th>Equipment Development, Integration &amp; Evaluation</th>
<th>Concept Proof Test, Demonstration</th>
</tr>
</thead>
<tbody>
<tr>
<td>2005</td>
<td>NiCT: Aero-broadband communication</td>
<td>Access control, Ground antenna</td>
<td></td>
<td>Mobile router, On-board access control</td>
<td></td>
</tr>
<tr>
<td>2006</td>
<td>NiCT: Technical survey &amp; Conceptual design</td>
<td>Partial trial-production</td>
<td>Access control, Ground antenna</td>
<td>Ground access control, Ground antenna</td>
<td></td>
</tr>
<tr>
<td>2007</td>
<td>Mitsubishi: Array antenna</td>
<td>Array antenna, RF module</td>
<td>Full array antenna</td>
<td>Ground access control, Ground antenna</td>
<td></td>
</tr>
<tr>
<td>2008</td>
<td>Mitsubishi: Equipment Development, Integration &amp; Evaluation</td>
<td>Mobile router, On-board access control, APAA</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Thank you for your kind attention...