Presentation 25, Session 5c:
ITU/BDT Regional Seminar on Broadband Wireless Access (BWA) for CIS, CEE and Baltic Countries,
Moscow (Russian Federation), 26-29 November 2007

Radio on Fiber & Free Space Optics Systems for Broadband Wireless Access

Katsutoshi Tsukamoto and Shozo Komaki
(Division of Electrical, Electronic and Information Engineering, Osaka University, Japan)
Mitsuji Matsumoto
(GITI, Waseda University, Japan)

tukamoto@comm.eng.osaka-u.ac.jp

Acknowledgements
This work is supported by a grant from the National Institute of Information and Communication Technology (NICT) of Japan.

Supported by NiCT

Abstract

In order to realize the ubiquitous networks, a combination of IP network and broadband heterogeneous wireless access services will play an important role. Users' demands for various types multimedia services will be increasing more and more; therefore full wireless IP connectivity will be required to accommodate variety of contents. Moreover, such diversification appears also in air interfaces of wireless access. A suitable wireless service should be provided according to users' different demands for applications, quality, latency, and moreover users' situations such as indoor, outdoor, and fast/slow mobility. Therefore, a universal platform for heterogeneous wireless services will become a key issue to realize ubiquitous networks.

In current wireless networks, however, various operators independently overlaid their own radio base stations and network. This leads redundant equipments and investments on infrastructures, and prevents the quick start of a new wireless service and employing microcellular architecture. These problems are revealed especially in in-building, underground at urban areas, and rural areas where broadband fiber-infrastructures have not yet been constructed due to their high cost and a low population.

Radio on Fiber (RoF) technologies can realize a cost effective universal platform for future ubiquitous wireless services. RoF can be extended into RoFSO (Radio on Free Space Optics) or RoR (Radio on Radio) networks, which provide a free space for heterogeneous wireless services in Free Space Optics or millimeter wave radio. We have started developing a new advanced RoFSO system.

This presentation describes its concept, features, and current technologies, and furthermore, discusses Radio on Fiber & Free Space Optics networks from a viewpoint of its role in future ubiquitous broadband wireless access.

3

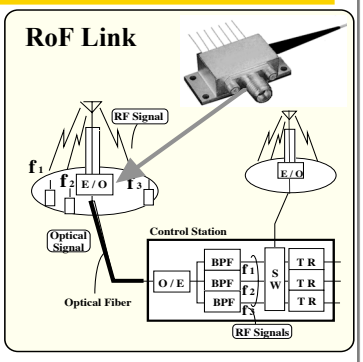
Outline

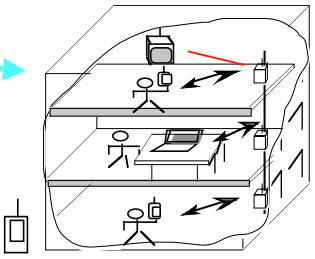
- Background
  - Radio on Fiber (RoF) Techniques and Current Applications
- Development of RoFSO (Radio on Free Space Optics)
  - Concept, Object and Features of Development
    - I. Development of Advanced DWDM RoFSO Link System
    - II. Development of Seamless Connecting Equipments amomg RoF, RoFSO and Wireless Systems
    - III. Long-term Demonstarative Mesurements
- Discussion in Role of RoF and RoFSO Technologies Towards Ubiquitous Broadband Wireless
  - Software Definable Radio Networks
- Conclusion

4

Benefits of RoF (Radio on Fiber) System in Current Wireless Access

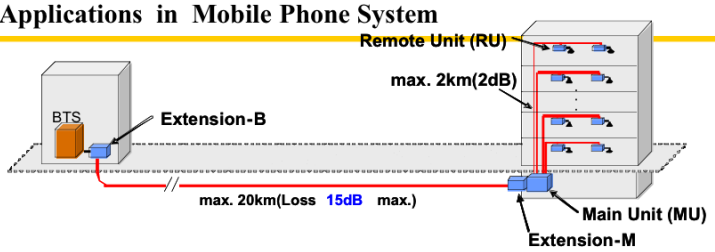
- RoF
  - transmit various types of radio signals by using wideband and low loss of optical fiber
  - reduce cost and complexity of radio base station
  - becomes a hopeful candidate of a common platform for various wireless access networks.
- Indoor applications
  - Difficulties in construction of diferent types of radio BSs and NWs
  - RoF network and universal RBSs can be easily and cost-effectively used with multioperaters
  - Ubiquitous Antenna Archtecture
    (RoF DAS: Distributed Antenna System)
    - expected to be one of the most used for indoor applications
      - achieve high frequency effiency
      - provide uniform capability coverage





Current Applications and Developments of RoF in Japan
RoF Applications in Mobile Phone System

5



Example of RoF applications for remote indoor coverage systems to reduce the area of indoor dead zone.

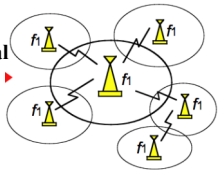
RoF Applications in public spaces such as underground stations and shopping center. Three operators commonly use one RoF feeder to provide 2G (800MHz, 1.5GHz) and 3G (2GHz) mobile phone services together.

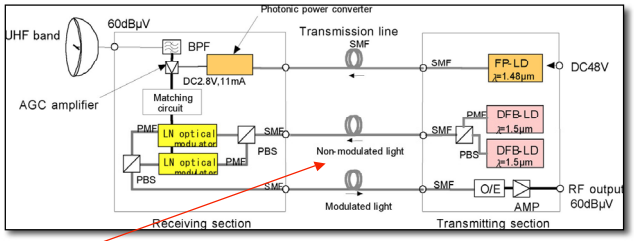
Courtesy of Panasonic Mobile Communications

RoF Applications in Broadcasting
Problem in DTV SFN and RoF solution

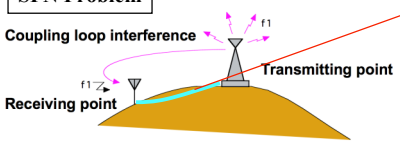
6

SFN for Digital TV relay network





SFN Problem



- **RoF is used in RF transmission between separated Transmitting and Receiving relay stations**
- **Receiving and transmitting points are kept away from each other by using RoF to reduce coupling loop interferences**
- **At the receiving equipment, DC power is supplied with high power light through another RoF link**

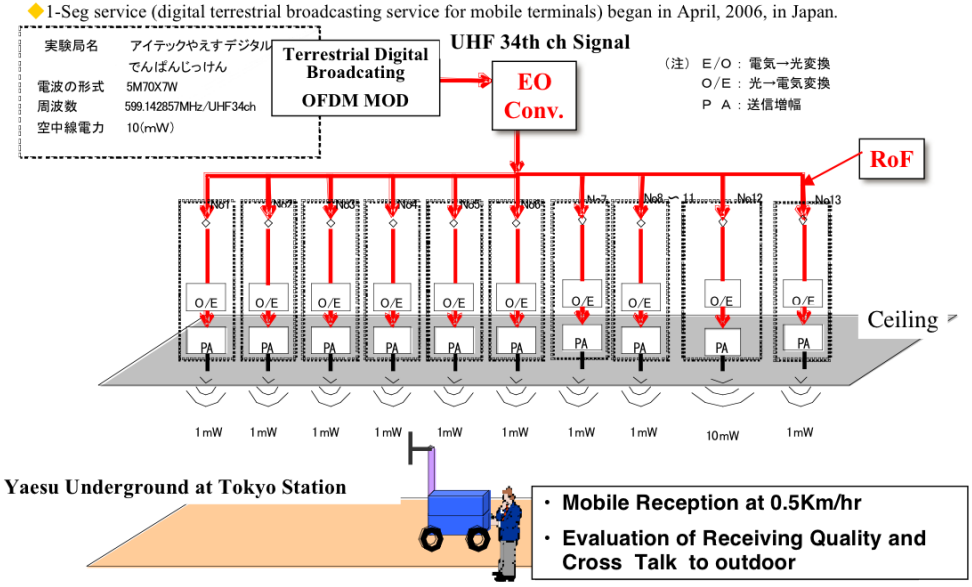
Y. Toba, et al.,"Development of a wide dynamic ranged radio wave receiving system with an optical modulator and DFB laser", *IEICE Trans, on Elec.*, vol. J88-C, pp. 99-106, Feb. 2005.
K. Haeiwa, "Recent Trends of Light-Micro Wave Fused Technology in Broadcasting", APMC2006 WS, Dec. 2006.
OITDA Feasibility Study Report of Microwave Photonics, 2005FY-009-2, March 2006

Experiment of RoF Application as Gap Filler for Mobile Reception of 1-Segment Digital TV

Experiment: Sept. 2005-Nov.2005
Commercial service started in April 2, 2007

7

◆1-Seg service (digital terrestrial broadcasting service for mobile terminals) began in April, 2006, in Japan.

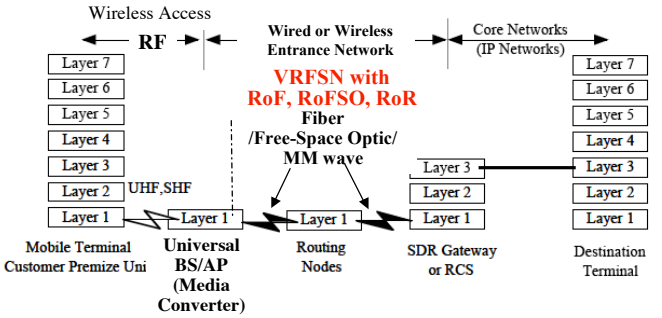


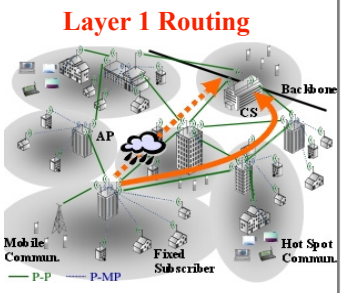
http://www.nhkitec.co.jp/001topics/2005/002/index.html

8

Virtual Radio Free Space Networking (VRFSN) realized by Layer 1 Routing

- **RoF : Common Platform (Universal backbone NW and APs) capability for various types of wireless services under multi air interferences coexistence**
- **Layer 1 Routing: Transparent routing for various air interfaces and protocols on L2, and upper**
- **Same Universality with RoFSO (Radio on Free-Space Optics) or RoR (Radio on Radio) Networks as RoF networks**
  - **Conversion of radio signals into FSO or MW/MMW signals with Heterodyne Frequency Conversion, and their non-regenerated repeat**
  - **suitable for Wireless Entrance Network in Indoor or Rural area**
- **FSO: No License, Wideband, Wireless (Quick start, Low investment)**





9

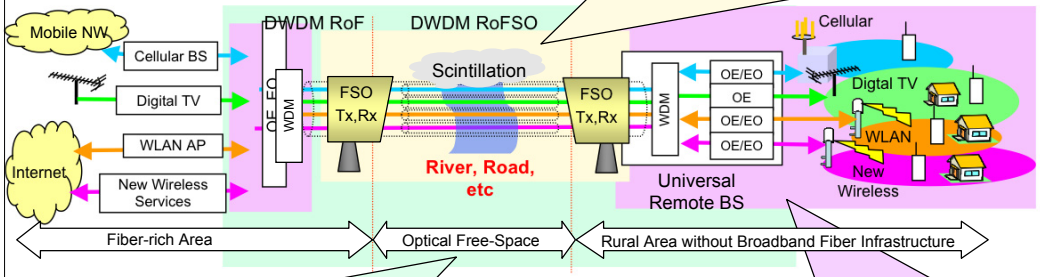
Development of RoFSO (Radio on Free Space Optics) System

- Osaka Univ. and GITI, Waseda Univ. started the development with financially support from NICT, Japan
- Development Term: Sept. 2006 - March. 2009
- Object:
  - To realize an effective provide of various types of wireless services for not only urban area but rural area, where has a little or no infrastructure for Broadband and Ubiquitous Services.
  - Develop 1.5 μm DWDM RoFSO link equipments
    - transparently transmitting cellular phones, wireless LAN, and terrestrial digital broadcasting services with 4 wavelength, and its long-term demonstration & evaluation.

10

Development of RoFSO (Radio on Free Space Optics) System

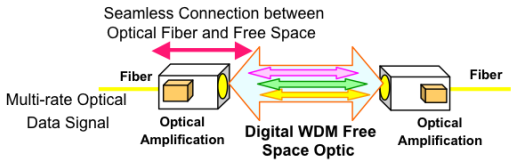
I. Development of Advanced DWDM RoFSO Link System
- Transparent and broadband connection between free-space and optcal fiber
- DWDM technologies for multiplexing of various wireless communications and broadcasting services



III. Long-term Demonstrative Mesurements
- Pragmatic examination of advanced RoFSO link system
- Investigation of scintillation influence on various types of wireless services transferred on RoFSO.

II. Development of Seamless Connecting Equipments between RoF, RoFSO and Wireless Systems
- Wireless service zone design
- Total link design through RoF, RoFSO, and Radio Links

Features of RoFSO Development

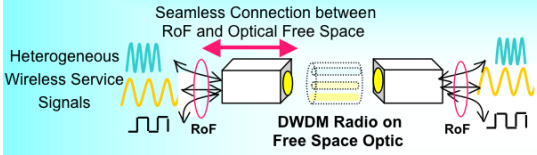


Next Generation FSO System

Protocol Free High Speed FSO link equivalent to Optical Fiber

Waseda Univ's Project supported by NICT

K. Kazaura, et. al. ,"Experimental Performance Evaluation of Next Generation FSO Communication System," AP-MWP 2006, vol. 1, pp. 289-292, April 2006.



Advanced DWDM RoFSO System

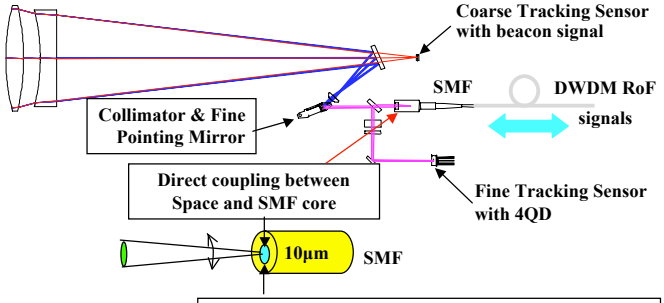
Full Transparent RoFSO for Heterogeneous Wireless Services equivalent to RoF

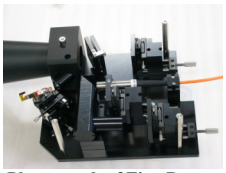
- employing direct optical amplification of DWDM RoF signals and emission into free space
- direct focusing a received optical beam into a core of SMF
- 1.5μm DWDM with more than 4 wavelengths for more than 4 different wireless services

I. Development of Advanced DWDM RoFSO Link System

- Development of RoFSO Transmitter / Receiver with Fine Beam Tracking Optic System
  - emit DWDM RoF signals from SMF into free space
  - direct focus a received optical beam into a core of SMF

Forward / Backward
Beam on single axis





Photograph of Fine Beam Tracking Optic System

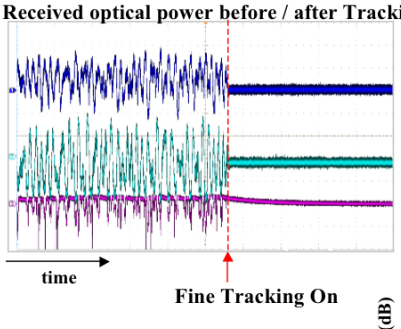
Photograph of prototype for an outdoor long-term demonstration experiment in 2008

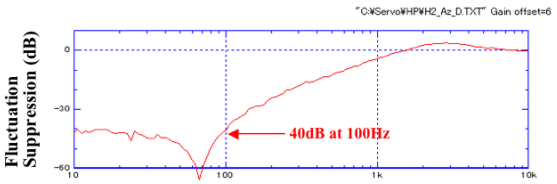
Objective Design Parameters

- Optical Transmitting Power : 20dBm/wave
- Geometric Loss: 2.6dB at 1km
  (Beam angle width : 47.3μrad at 1.55μm)
- Equipment Loss : < 10dB (Tx & Rx total)

Evaluation of Suppression Capability of Fine Tracking for Received Optical Power Fluctuation due to Random Angle-of-Arrival and Scintillation

Received optical power before / after Tracking

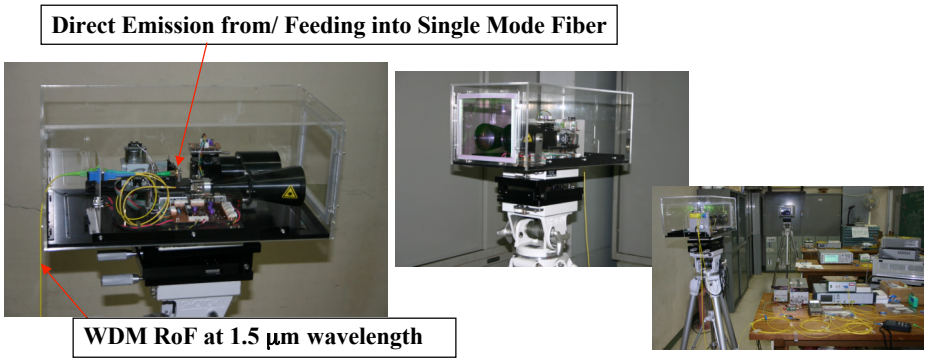




Next step: **40dB suppression at several KHz**

II. Development of Seamless Connecting Equipments among RoF, RoFSO and Wireless Systems

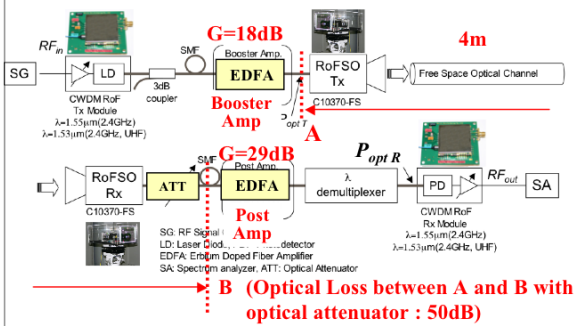
Photograph of RoFSO equipment (Prototype) for basic indoor short-range transmission experiment of RF signals on Free Space Optics



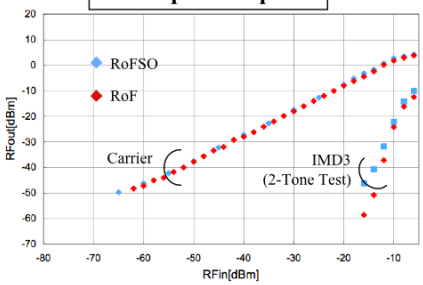
15

Basic Confirmation of FSO Loss Compensation with Optical Amplifier

Indoor short range experiment setup



RF output vs input



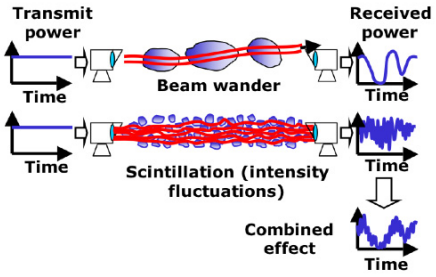
RoFSO link equivalent to RoF, without IMD3 increase by using Booster and Post EDFA

1.55μm WLAN (2.4GHz) LD &PD module.
RoFSO w/ EDFA at both TX and Rx.
Optical Loss between Tx and Rx: 50dB
$P_{opt\,R}$ = -3.75dBm
RoF w/o EDFA at both TX and Rx.
Optical Loss between Tx and Rx: 6dB
$P_{opt\,R}$ = -3.3dBm

16

III. Long-term Demonstarative Mesurements

- **Atmospheric turbulence**
  - **has a significant impact on the quality of the free-space optical beam.**

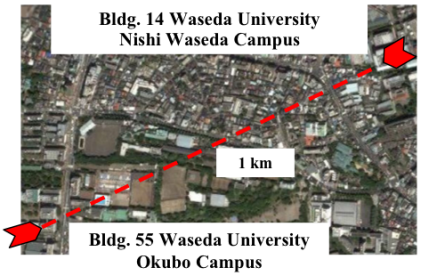


Beam broadening and angle-of-arrival fluctuations (slow)

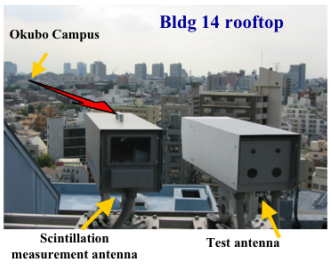
Intensity fluctuations (fast)

Reduces the received optical beam power, and causes fading and burst errors in transmitted RF signals

Experiment setup at Waseda Univ., Tokyo

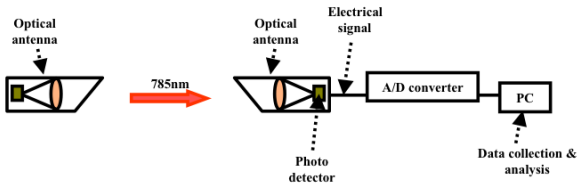


Experiment field



Rooftop setup

Measurement setup with conventional 800nm FSO system

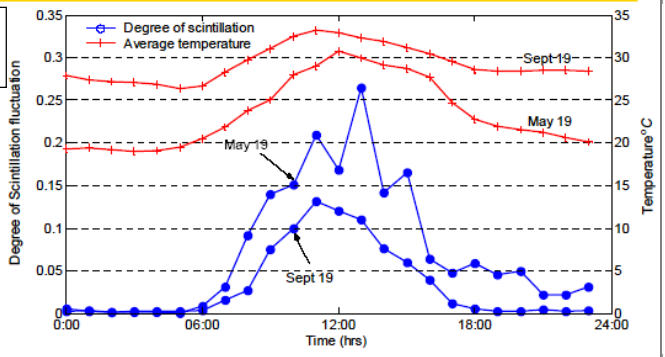


Scintillation Variance

Measurement results of Scintillation variance versus time in a day in May or September

Large variation in temperature

Large variation in variance



Further study:

- **Long-term Scintillation Measurement**
- **Stochastic Model Construction of RoFSO channel**
- **Evaluation its influences (burst error) on four types of transmitted RF signals transmitted on RoFSO link**

19

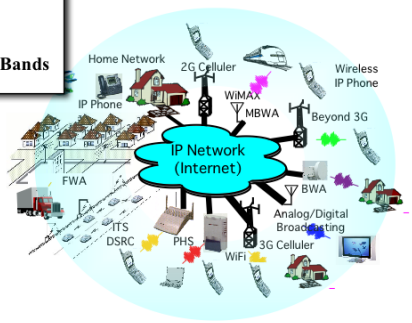
Discussion in Role of RoF Technologies Towards Ubiquitous Wireless Network

- Ubiquitous Network
  - Communication environments for any user to access any communication service at any time, any place, and any situations
  - Accommodate any users' demand for various types of multimedia services

Diversification in Wireless Access

- Various types of Wireless Access systems
  - 2G/3G/3.5G/4G cellular, WiFi, WiMax, UWB, Ad-Hoc etc
  - Depending on coverage, allocated frequency band, etc.
- Diversification appears in air interfaces
  - Modulation Formats, Media Access Protocol, Speed, Frequency Bands

Heterogeneous Wireless Access in Ubiquitous Network



20

Diversification in User's Demand for Broadband Wireless Service

Diversification in Wireless Access Methods and Users' demands

- Same diversification appears in
  - Users' different demands for applications and service quality
  - Users' different situations (indoor/outdoor, and fast/slow mobility)
    - VoIP phone: Continuity under Mobility, No Delay, No Congestion
    - Web download: High speed, Multimedia Download, No Latency

Requirement: Common Platform for various types of wireless services under the multi air interferences coexistence with User Centric Seamless System Handover Function

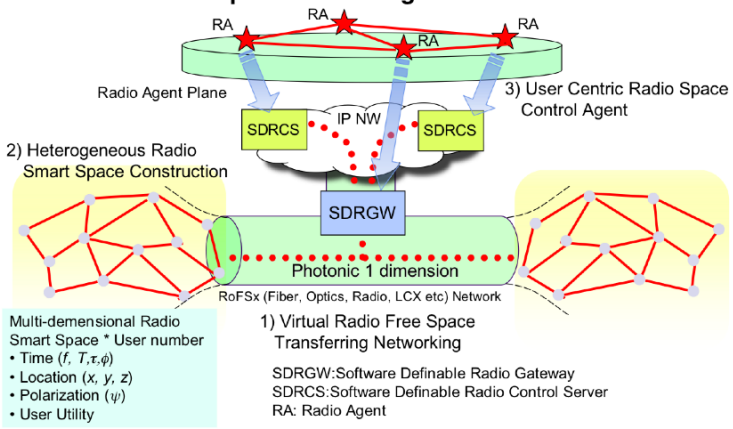
Proposed Solution: Software Definable Radio Networks (SDRN)

RoFSx (RoF, RoFSO, RoR) Networks + SDRGW + Wireless Service Over IP + Radio Agents

Software Definable Radio Networks (SDRN)

= RoF Network + SDRGW + Wireless Service Over IP + Radio Agents

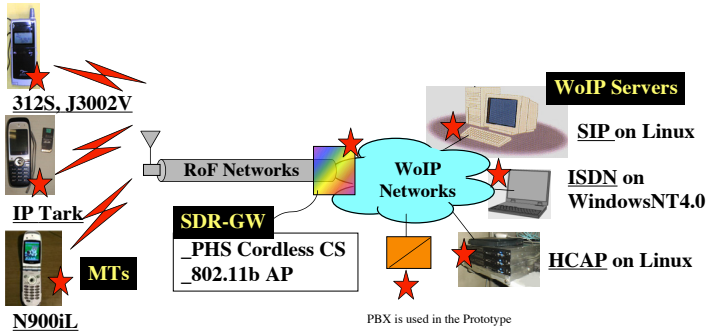
- **Following features:**
  1) **Virtual Radio Free Space Transferring Networking**
  2) **Heterogeneous Radio Smart Space Construction**
  3) **User Centric Radio Space Control Agent**



1) Virtual Radio Free Space Transferring Networking with RoF, SDRGW and WoIP

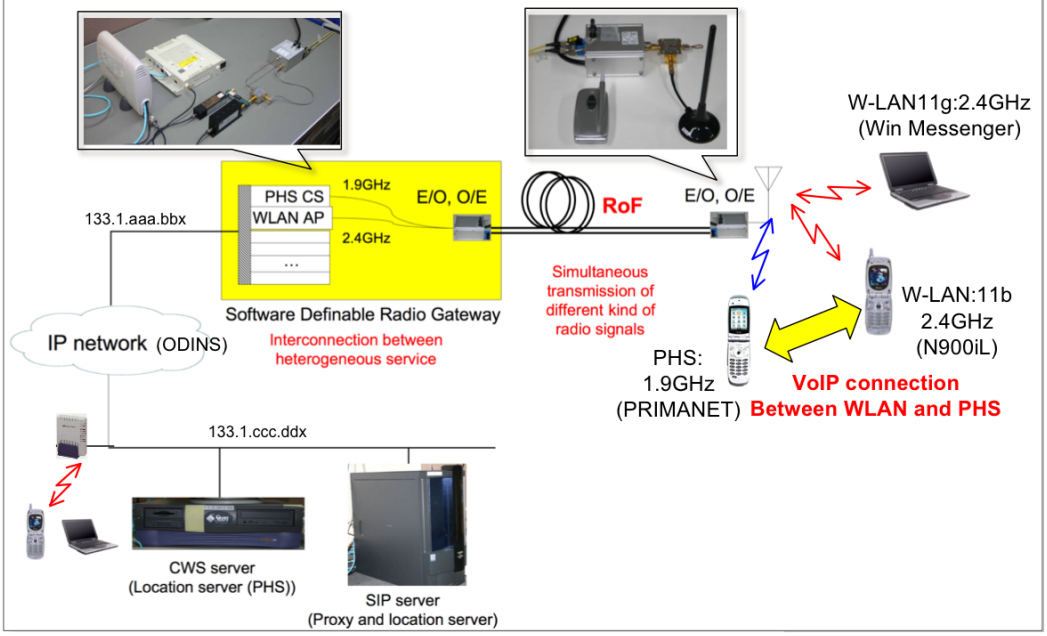
- **SDRGW:**
  - **Air interface conversion among different radio services**
  - **Conversion of data in radio signal into IP packet**
  - **Transfer radio signals over IP NW to its CS altogether with the control channel signal**

- **Wireless Service over IP (WoIP) Networks**
  - **a cross layer platform on IP networks for Heterogeneous Wireless Services.**



23

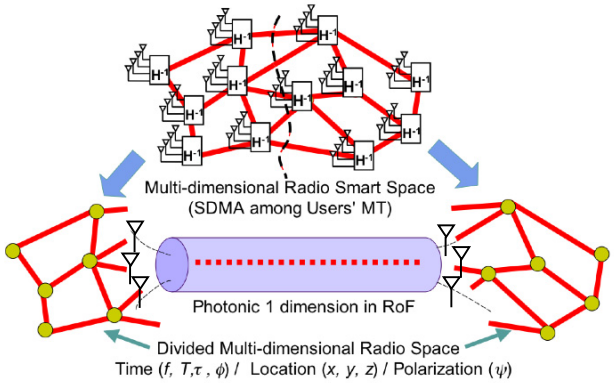
RoF+SDRGW+WoIP Prototype



24

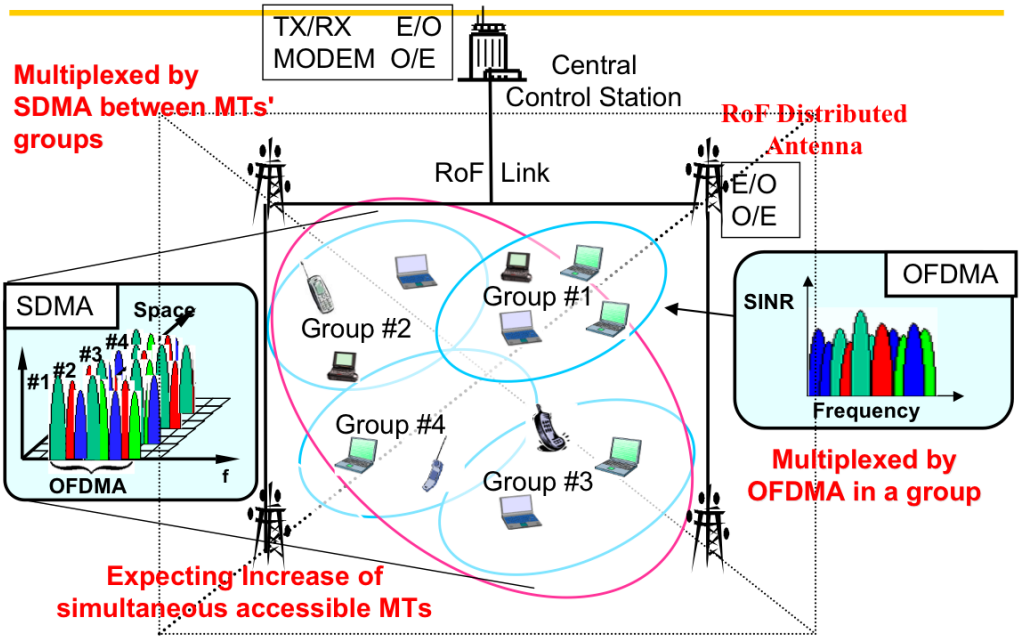
2) Heterogeneous Radio Smart Space Construction & Transmitting

- **Wireless Access toward cooperative P-P connection among MT's.**
- **MIMO and Interference Cancellation realize Co-channel SDMA Radio Smart Space.**
- **Heterogeneous multi-dimensional radio spaces are composed with each smart radio space around each of mobile terminals, which are often away from each other**
- **RoF networks with multi antenna can transparently connect these divided radio spaces each other transparently with their air-interfaces.**



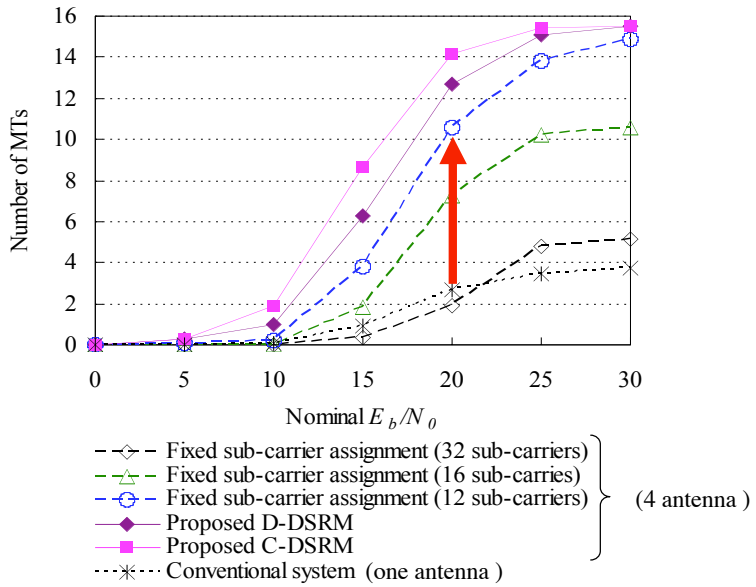
25

Simulation Evaluation of SDMA supported by RoF Distributed Antenna



26

Simulation Results

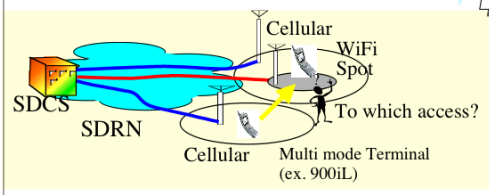


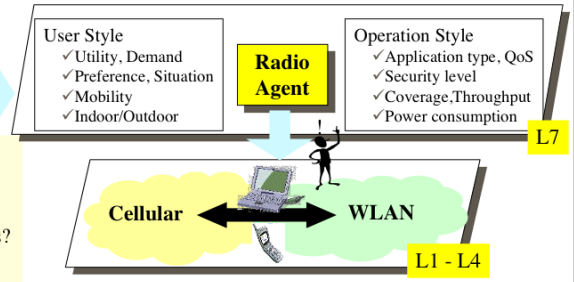
27

3) User Centric Radio Space Control Agent

- SDRN can realize Frequency Spectrum Delivery according to Users' and Operators' Demand.
- Even if accessing the same wireless service, users' demands and utilities are different, depending on their preference, mobility and situations
- Radio Agents
  - to realize User Centric Session Handover/ Service Handover/ Radio Resource Management in Wireless Heterogeneous Network
  - equipped at User Terminal, SDRGW and IP Network as middle ware on Layer 7

Example :
User Centric Wireless Media Handover Agent





User Centric Wreless Media Handover

28

Conclusions

- As Background
  - Radio on Fiber Techniques and Their Current Applications and Developments
  - Layer 1 Routing and Radio on Free Space Link
- Development of RoFSO system
  - Full Transparent RoFSO for Heterogeneous Broadband Wireless Services equivalent to RoF
  - Sept. 2006 - present
    - Developed RoFSO link equipments transmitting more than 4 different wireless services with DWDM techniques.
    - Basic experimental confirmation of loss compensation with EDFA
    - Started long-term scintillation measurements and evaluation of its impact on RF signals on FSO
  - We will conduct a long-term demonstrative experiment in 2008.
- Toward Ubiquitous Heterogeneous Wireless Service Networks,
  - Software Definable Radio Networks (SDRN) will be available as a Common Platform for various types of wireless services under the multi air interferences coexistence.
  - Heterogeneous Radio Smart Space Construction & Transmitting
    - RoF networks with multi antenna can transparently connect these divided radio spaces each other transparently with their air-interfaces.