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WiMax - μ



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WiMax - μ

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802.16
 WiMax.

μ μ , WiBro, WiMax Forum,
 μ μ 802.11 WiFi,
 , μ WiMax OSI.
 Data Link MAC
 LLC . μ μ μ
 μ , μ μ duplexing. μ
 μ
 WiMax. ,
 μ
 . WiMax WiFi.
 μ WiMax μ ,
 WiMax . ,
 μμ ομ MSITE.

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μ

3DES	Triple Data Encryption Standard
AAA	Authentication, authorization, and accounting
Ack	Acknowledgment
AES	Advanced Encryption Standard
AK	Authorisation Key
AP	Access Point
APEC	Asia Pacific Economic Cooperation
AR	Authorisation Reply
ASN	Access Service Network
ATM	Asynchronous Transfer Mode
AWS	Advanced wireless services
BPSK	Binary Phase Shift Keying
BRS	Broadband radio services
BS	Base station
BSID	Base Station ID
BTC	Block Turbo
BTC	Block Turbo Coding
BWA	Broadband Wireless Access
CC	Convolutional Code (Tail-biting)
CDMA	Code Division Multiple Access
CFP	Contention-free period
CHAP	Challenge handshake authentication protocol
CID	Connection Identifier
CMAC	Cipher-based Message Authentication Code
CP	Contention period
CPS	Common Part Sublayer
CS	Convergence Sublayer
CSMA/CA	Carrier Sense Multiple Access with Collision Avoidance
CSN	Connectivity Service Network
CTC	Convolutional Turbo Codes
DCD	Downlink Channel Descriptor MAC
DCF	Distributed coordination function
DES	Data Encryption Standard
DFS	Dynamic Frequency Selection
DLL	Data Link Layer
DOCSIS	Data Over Cable Service Interface Specification
DS	Direct sequence
DSSS	Direct Sequence
EAP	Extensible authentication protocol
EAP-SIM	Subscriber identity module
EAP-TLS	EAP-transport-layer security
ETSI	European Telecommunications Standards Institute

Extended EAP	Extensible Authentication Protocol	
E		μ
FCC	Frequency Division Duplexing	
FDD	Frequency Division Duplexing	
FEC	Forward Error Correction	
FH	Frequency hopping spread spectrum	
FHSS	Frequency Hopping	
FIPS	Federal Information Processing Standard	
HIPERMAN	High Performance Radio MAN	
HMAC	Hashed Message Authentication Code	
H	H	μ
IETF	Internet Engineering Task Force EAP	
IIoT	Infrastructure Interoperability Testing	
IOT	Interoperability Testing	
IP	Internet Protocol	
IR	Infrared	
ISM	Industrial Scientific and Medical	
ISP	Internet service provider	
LAN	Local Area Network	
LDPC	Low Density Parity Check	
LLC	Logical Link Control	
LOS	Line Of Sight	
MAC	Media Access	
MAN	Metropolitan Area Network	
MBWA	Mobile Broadband Wireless Access	
MDS	Multi-point distribution services	
MIB	Management information base	
MIOT	Mobile Interoperability Testing	
MPDU	MAC PDU	
MSB	Most Significant Byte	
NCT	Network Conformance Testing	
NLOS	Non Line Of Sight	
Oc-H	Optical Carrier Level	
OFDM	Orthogonal Frequency-Division Multiplexing	
OFDMA	Orthogonal Frequency Division Multiple Access	
P2P	Point-to-point Backhaul	
PAN	Personal Area Network	
PAP	Password authentication protocol	
PCF	Point coordination function	
PCMCIA	Personal Computer Memory Card International Association	
PCT	Protocol Conformance Testing	
PDA's	Personal digital assistants	
PEAP	Protected EAP	
PHS	Payload Header Suppression	
PKI	Public Key Infrastructure	
PKM	Privacy Key Management	

PKMv2	Privacy Key Management Version 2
PMP	Point-to-Multipoint, last mile
PPP	Point-to-point protocol
PRBS	Pseudo-Random Binary Sequence PRBS
PSs	Physical Slots
PTM	Point to multipoint
QAM	Quadrature Amplitude Modulation
QPSK	Quadrature Phase Shift Keying
RADIUS	Remote Access Dial-In User Service
RCT	Radio Conformance Testing
RF	(
RPT	Radiated Performance Testing
RSA	Rivest-Shamer-Adleman
RS-CC	Reed–Solomon Convolution Code
SAR	Absorption Rate
SC	Single Carrier
SOFDMA	Scalable OFDMA
SS	Subscriber station
TCS	Transmission Convergence Sublayer
TDD	Time Division Duplexing
TDM	Time Division Multiplexing
TDMA	Time Division Multiple Access
TPC	Transmit Power Control
TTA	Telecommunications Technology Association
T	Temporal Key Integrity Protocol
U-NII	Unlicensed National Information Infrastructure
VPN	virtual private network
WCB	WiMax WiMax Certification Body
WECA	Wireless Ethernet Compatibility Alliance
WFDCLs	WiMax Forum Designated Certification Labs
WiBro	Wireless Broadband
WiFi	Wireless Fidelity
WiMax	Worldwide Interoperability for Microwave Access
Wireless HUMAN	High-speed Unlicensed Metropolitan Area Network
WLAN	Wireless Local Area Network
WPA	WI-Fi Protected Access
WPAN	Wireless Personal rea etworks
xDSL	Subscriber Line technologies
ZT CC	Zero-Tailing Convolutional Code

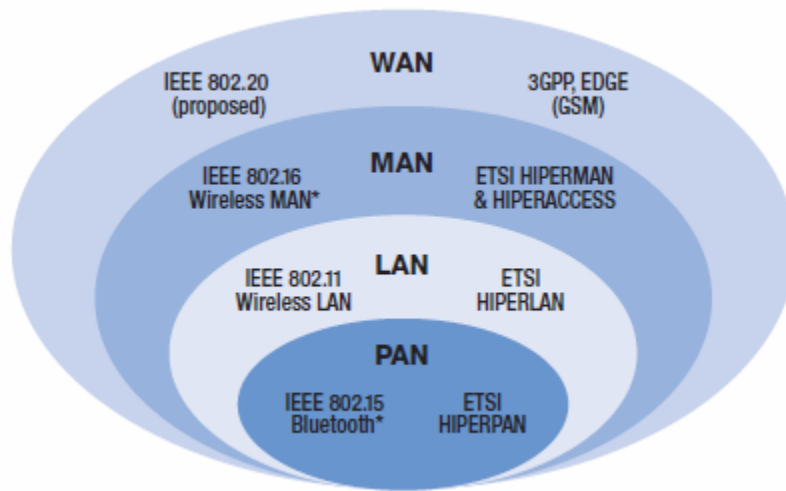
1-1. μ μ

1.1.1

μ μ μ μ

μ μ

μ μ



μ 1.1: μ . [3]

(Personal Area Network, PAN)

μ μ μ μ

μ 10 μ μ

μ 15 μ Bluetooth, UWB

Zigbee.

(Local Area Network, LAN)

μ μ μ μ :

(personal digital assistants, PDAs).

μ μ μ μ LAN

100 μ μ μ μ LANs Ethernet (

LAN) WiFi (μ LAN WLAN).

(Metropolitan Area Network, MAN)
 LANs.
 MAN WiMax.
 (Wide Area Network, WAN)
 LANs,
 WAN 3G
 EDGE. [1]

1.1.2 IEEE 802



1979
 1980 (80/2), IEEE 802,
 LANs MANs. IEEE 802
 IEEE 802.2, Logical Link Control (LLC).
 IEEE 802.3, Ethernet. LANs. LAN.
 IEEE 802.5, Token Ring. Token Ring LAN
 '80.
 10BASE-T Ethernet '90.
 IEEE 802.11, WLAN. IEEE 802.11 (WLAN),
 WiFi. IEEE 802.11
 1990. WiFi

2,4 GHz 5 GHz

IEEE 802.15, (Wireless Personal Area Networks, WPAN). Bluetooth

IEEE 802.11, (Wireless Local Area Networks, WLAN). WiFi

IEEE 802.16, (Broadband Wireless Access, BWA). WiMax (Worldwide

Interoperability for Microwave Access). IEEE 802.16

IEEE 802.16, (Broadband Wireless Access, BWA). WiMax (Worldwide Interoperability for Microwave Access).

IEEE 802.16-2004, IEEE 802.16e, IEEE 802.16-2004

IEEE 802.20, Mobile Broadband Wireless Access (MBWA). MBWA

1.1.3 WiMax

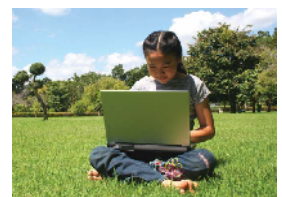
WiMax (Worldwide Interoperability for Microwave Access) IEEE 802.16 (Wireless MAN).

ETSI (European Telecommunication and Standards Institute)

HIPERMAN (High Performance Radio MAN)

WiBro (Wireless Broadband)

WiFi, WiFi, WiMax 70Mbps.



50km
 sight (LOS)
 10 Mbps
 10Mbps
 100

WiMax
 70 Mb/s,
 line-of-
 30%
 DSL
 SDSL
 WiMax
 100Mbps backhaul
 2, 4, 6, 8 10 Mbps
 GSM UMTS
 802.16 MAC

- WiMax
 WiMax.
 WiMax



- WiMax. μ
- μ PCMCIA (Personal Computer Memory Card International Association) μ
- μ μ μ
- Wi-Fi.



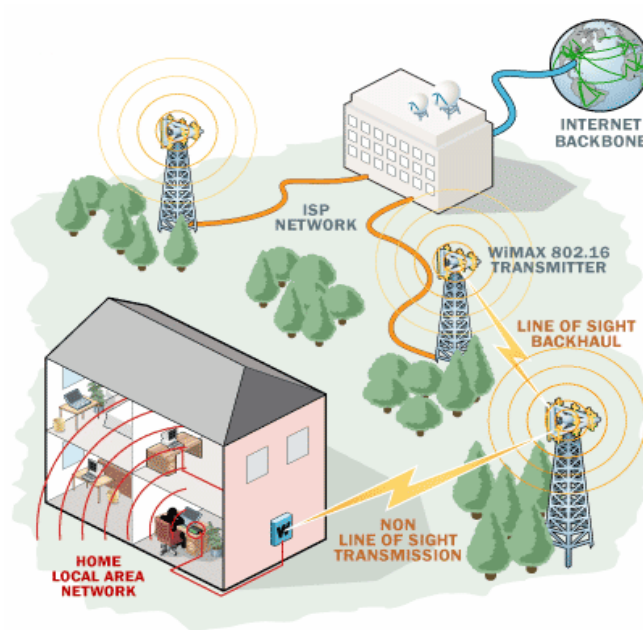
WiMax μ μ μ μ

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μ WiMax μ μ

μ μ μ

μ μ μ



μ 1.2: μ . [9]

802.16

MAC

μ μ μ

best effort

μ . , WiMax

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DES (Data Encryption Standard) μ μ

μ Triple DES. DES

$\mu\mu$

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μ μ

56bit.

μ

Triple-DES μ μ

μ

μ

, μ

. [1, 6]

1-2. 802.16

H μ WirelessMAN
 1998. 2001 802.16 .
 μ :

1.2.1 802.16-2001

To 802.16 2001 2002. μ
 μ 10 66 GHz, μ 20, 25 28 MHz
 μ . μ
 Data Over Cable Service Interface Specification
 (DOCSIS). μ μ hybrid fiber-coaxial
 (HFC) BWA. μ
 μ μ
 μ μ ,
 μ μ μ μ
 μ .

1.2.2 802.16c

802.16-2001 μ μ
 μ
 μ μ .

1.2.3 802.16a-2003

μ μ μ 2003
 μ μ μ 2 11 GHz. μ
 μ
 μ μ μ
 μ IEEE 802.16a PTP
 mesh air interfaces:

- WirelessMAN-SC single-carrier modulation
- WirelessMAN-OFDM μ 256 point transform
- WirelessMAN-OFDMA μ 2048-point transform.

WiMax

μ

μ

μ

1.2.4 802.16 d

1.2.5. 802.16-2004

802.16c-2002 WiMax

μ

802.16d -2001, 802.1a-2003,
802.16-2004

μ

μ

base

station (BS).

base station

μ

2-66 GHz

PTP

mesh.

μ

μ

μ

air interfaces:

- WirelessMAN-SC 10-66GHz
- WirelessMAN-SCa μ <11GHz
- WirelessMAN-OFDM μ <11GHz
- WirelessMAN-OFDMA μ <11GHz
- WirelessHUMAN μ μ <11GHz

μ

μ

μ

μ

1.2.6 802.16e (mobile WiMax)

802.16e

μ

2005

802.16

μ

base station

μ

μ

μ

120 Km/h.

μ

OFDMA

NLOS.

μ

μ

OFDMA (Scalable OFDMA, SOFDMA)

1.25

20MHz.

5, 7, 8.75

10MHz
 μ downlink
 μ 63Mbps, uplink
 2.3, 2.5
 28Mbps
 (PDAs) notebook
 3.5GHz
 laptop.
 10 Hz.

1.2.7 IEEE 802.16f-2005

PHY
 IEEE 802.16
 IEEE 802.16-2004
 (management information base, MIB)
 MAC
 μ
 μ
 μ

1.2.8 IEEE 802.16g-2007

IEEE 802.16e-2005
 μ
 IEEE 802.16f-2005
 MAC
 PHY
 IEEE 802.16-2004,
 μ
 IEEE 802.16

1.2.9 IEEE 802.16k

MAC.
 μ IEEE 802.16

1.2.10 IEEE 802.16-2009

IEEE 802.16,
 μ IEEE 802.16-2001 IEE 802.16-2004 . μ μ
 IEEE 802.16-2004, 802.16e-2005, 802.16f-2005 802.16g-2007 .
 μ IEEE
 μ μ 2009.

1.2.11

μ μ μ
 μ μ ITU IMT-Advanced .

IEEE 802.16h

IEEE P802.16m. IEEE 802.16e-2005, IEEE 802.16m

[12, 20, 21, 23, 39]

	802.16	802.16-2004	802.16e-2005
Status	Completed December 2001	Completed June 2004	Completed December 2005
Frequency band	10GHz–66GHz	2GHz–11GHz	2GHz–11GHz for fixed; 2GHz–6GHz for mobile applications
Application	Fixed LOS	Fixed NLOS	Fixed and mobile NLOS
MAC architecture	Point-to-multipoint, mesh	Point-to-multipoint, mesh	Point-to-multipoint, mesh
Transmission scheme	Single carrier only	Single carrier, 256 OFDM or 2,048 OFDM	Single carrier, 256 OFDM or scalable OFDM with 128, 512, 1,024, or 2,048 subcarriers
Modulation	QPSK, 16 QAM, 64 QAM	QPSK, 16 QAM, 64 QAM	QPSK, 16 QAM, 64 QAM
Gross data rate	32Mbps–134.4Mbps	1Mbps–75Mbps	1Mbps–75Mbps
Multiplexing	Burst TDM/TDMA	Burst TDM/TDMA/ OFDMA	Burst TDM/TDMA/ OFDMA
Duplexing	TDD and FDD	TDD and FDD	TDD and FDD
Channel bandwidths	20MHz, 25MHz, 28MHz	1.75MHz, 3.5MHz, 7MHz, 14MHz, 1.25MHz, 5MHz, 10MHz, 15MHz, 8.75MHz	1.75MHz, 3.5MHz, 7MHz, 14MHz, 1.25MHz, 5MHz, 10MHz, 15MHz, 8.75MHz
Air-interface designation	WirelessMAN-SC	WirelessMAN-SCa WirelessMAN-OFDM WirelessMAN-OFDMA WirelessHUMAN ^a	WirelessMAN-SCa WirelessMAN-OFDM WirelessMAN-OFDMA WirelessHUMAN ^a
WiMAX implementation	None	256 - OFDM as Fixed WiMAX	Scalable OFDMA as Mobile WiMAX

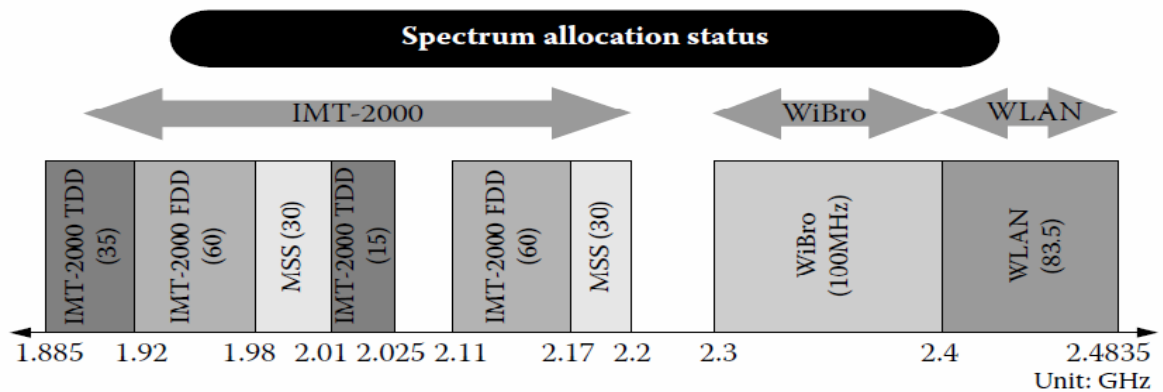
1.1: IEEE 802.16 [4]

Samsung μ WiBro
 μ video calling
 μ μ μ downlink 2 Mbps
 μ 120 μ .

1.3.2 WiBro μ
 Times μ
 WiBro Samsung μ \$3-
 μ μ . WiMax μ
 μ μ μ μ .

1.3.3 WiBro
 WiBro μ ,
 « μ WiBro» .
 μ μ PDAs laptop μ
 PCMCIA WiBro μ WiBro ,
 μ .

1.3.4 WiBro
 μ
 WiBro μ μ μ
 , . WiBro
 . Samsung, μ μ μ 2.3-
 GHz, 2.5-GHz 3.5-GHz . [1]



μ 1.3: μ μ WiBro. [1]

1 – 4. WiMax Forum

1.4.1

μ WiMax μ μ μ
μ μ μ
WiMax.
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μ μ μ .
μ μ WiMax μ
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μ μ . μ μ
WiMax.
μ WiMax μ μ
μ μ
μ , μ , μ
μ μ μ . μ
μ IEEE (Institute of Electrical and Electronics Engineers)
ETSI (European Telecommunications Standards Institute), μ ,
530 μ μ WiMax μ μ
μ μ WiMax.
μ WiMax. μ μ
μ μ μ , μ
WiMax μ μ μ μ
μ μ
μ MAC .
μ , μ μ
MAC μ μ
μ μ WiMax
μ μ IEEE 802.16 ETSI HiperMAN
μ μ
μ WiMax μ μ
μ WiMax. μ μ



μ WiMax μ
 μ μ WiMax
 .
 «WiMax Forum» μ μ μ
 μ WiMax. "WiMax," μ
 WiMax, «WiMax Forum Certified» μ μ
 μ WiMax. μ
 μ .
 Forum μ

Alvarion, Motorola, Samsung Sequans Communications
 μ μ (CPE) Airspan Networks,
 Baceem Communications, Intel, ZyXEL, Samsung Sequans Communications.
 WiMax Forum μ μ 2011
 mobile WiMax.

WiMax μ μ μ
 μ μ . μ

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 μ WiMax μ
 WiMax .
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1.4.2

WiMax Forum® 2001
 500 μ . μ
 WiMax Forum™: , (Regular,
 Principal, Board).
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 WiMax μ . μ
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 WiMax μ . , μμ
 , . , μ
 μ μ μ WiMax
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5. WiMax Forum Certified μμ
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 WiMax μ
 μ μ μ μ μ ,
 μ μ μ μ μ . μ
 WiMax μ
 μ WiMax, μ μ μ μ , μ
 , chipset μ μ ,
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 , , ,
 WiMax Forum Designated Certification Labs (WFDCLs)
 μ μ μ WiMax, μ
 μ μ μ
 WiMax, μ μ μ
 μ WiMax. μ μ
 μ μ Agilent, Anite, AT4, Azimuth, Innowireless,
 Tektronics, Rohde and Schwarz, Sanjole. μ
 , WFDCL μ WiMax.
 WFDCLs μ
 CWG μ .
 , , ,

μ WiMax

1.4.4

μ μ

μ :

:

- Radio Conformance Testing (RCT) μ
- Protocol Conformance Testing (PCT) μ
 MAC, μ μ μ μ ,
 Media Access Control Common Part Sublayer Service
 Specific Convergence Sublayer.
- Interoperability Testing (IOT) Mobile Interoperability Testing (MIOT)
 μ μ
 μ μ μ
 μ .
 :
- Radiated Performance Testing (RPT) μ
 μ μ μ
 (μ),
 , μ (, , μ
) . μ
 2009.
- Network Conformance Testing (NCT) μ μμ
 μ MAC
 (IP), μ .
- Infrastructure Interoperability Testing (IIOT)
 Access Service Network (ASN) Connectivity Service Network (CSN)
 μ μ
 μ .

Open Systems Interconnection (OSI) model	WiMAX Specifications	Certification modules
Application layer	WiMAX Forum Network Specifications	NCT, IIOT
Presentation layer		
Session layer		
Transport layer		
Network layer		
Data link layer– Logical Link Sublayer		
Data link layer – Media Access Control (MAC) layer	WiMAX Forum System Specifications (based on IEEE 802.16)	PCT, IOT, MIOT
Physical (PHY) layer		RCT, IOT, MIOT, RPT

μ 1.4: OSI, . [11]
 RCT, PCT, RPT μ IEEE 802.16
 ETSI HiperMAN MAC . IOT, MIOT,
 NCT IIOT μ WiMax Forum Network

1.4.5

μ WiMax μ
 ,
 μ μ ,
 μ .
 μ ,
 μμ μ : μ WiMax
 μ WiMax.
 μ 2006 WiMax,
 μ WiMax
 μ 2008. μ μ WFDCL
 , μ , μ
 μ , . μ

μμ plugfests μ WiMax μ,

μ μμ μ

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μ μ μ

3.

μ μ

μ μ μ

μ μ μ

. , μ μ

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, , , μ

μ

μ μ μ

4.

μ , μ

WiMax (WiMax Certification Body, WCB)

WiMax Forum Certified Product Registry

μ

μ

μ. [11, 36]

1.5.7

(Administration)

Wizards ().

1.5.8

laptops, NOP World—Technology Cisco Systems , 45

1.5.9 WiMax

WiMax

- **Broadband on Demand.**

802.11 μ

-

μ μ μ μ μ μ μ μ



. [16, 38]

IEEE 802.11
(WLAN)

IEEE 802.3
«WiFi». WiFi Alliance

IEEE,
802.11.

WiFi (Wireless Fidelity)

2.4 GHz.

WiFi («

IEEE 802.11 b/g

μ

μ

)

μ
μ

(VoIP)

μ

Internet,

μ

μ , DVD Player

WiFi

μ

μ
μ

μ

μ

μ

μ

Ethernet

μ

μ

μ

μ

μ

μ

μ

μ

WiFi Alliance

μ



μ

μ

μ

WiFi.

WiFi Alliance

Wireless Ethernet Compatibility
1999

Alliance (WECA)

μ

WLAN.

μ

μ

μ

802.11

LAN

μ

μ

μ

μ

μ

μ

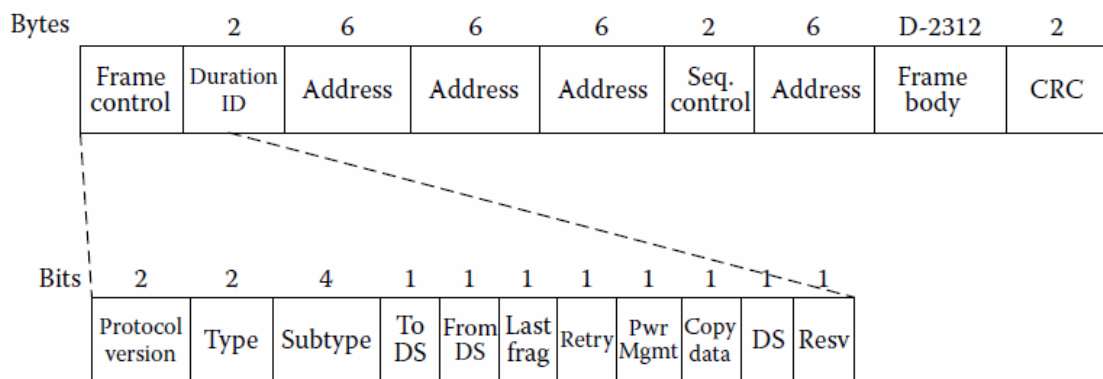
μ

WiFi

μ

μ

MAC. PCF μ polling
 μ (access point) μ
 μ .
 μ , DCF,
 CSMA/CA (Carrier Sense Multiple Access with Collision Avoidance). μ μ
 (CD), μ CSMA/CD
 Ethernet, μ μ 802.11. μ
 μ , μ μ
 μ , μ .
 μ μ , μ μ .
 μ μ , μ
 μ . acknowledgment (ack)
 μ , μ μ
 . 802.11
 : , μ .
 μ μ μ access
 point, μ .
 μ (handshaking)
 μ CP (contention period),
 CP contention-free period (CFP).
 μ μ μ CP
 CFP μ μ polling acknowledgments.



μ 2.1: 802.11 μ . [6]

2.4 GHz (ISM)

HomeRF (Industrial Scientific and Medical)

Frequency Hopping (FHSS)

1 Mbps, Direct Sequence (DSSS)

1 μ 2 Mbps. (IR). 802.11

802.11b

11 Mbps DSSS. 1 μ 2 Mbps

μ DSSS

WiFi

802.11

Orthogonal Frequency Division Multiplexing (OFDM), 802.11g

54 Mbps, 802.11a

5GHz

802.11b, 802.11g

2.4 GHz

802.11b. 802.11b

802.11g, 802.11b.

WiFi 2000 μ

Internet: μ

WiFi, . . . PDA, μ

(Access Point).

μ μ

hotspot. hotspot μ

WiFi μ μ μ μ .

internet.

2.6

WPA WPA2
 WiFi
 access point,
 SSL
 (virtual private network, VPN).
 WPA WPA2
 Extended EAP (Extensible Authentication Protocol) WI-Fi
 Protected Access (WPA) WPA2 Enterprise certification programs,
 WiFi
 . [6, 19]

2.7

IEEE 802.11

- 802.11, 1997.
- 802.11b, 1999.
- 802.11a, 1999.
- 802.11g, 2003.



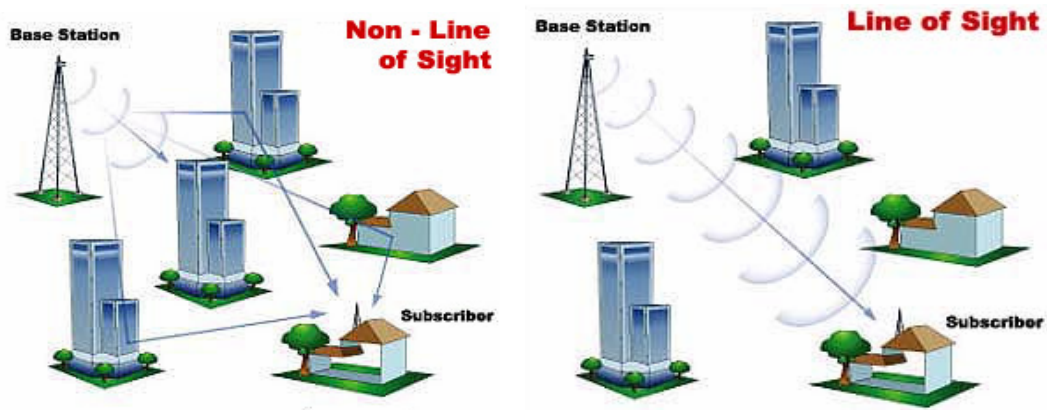
802.11f IAPP,
 AP
 .

3 -

3.1

WiMax
DSL (ISP).
mobile WiMax
WiFi,
WiMax. [18, 40]
: line-of-sight non-line-of-sight.
(line-of-sight),
WiMax line-of-sight
66 GHz.
WiMax (non-line-of-sight, NLOS),
NLOS
2-11 GHz (WiFi). [18, 40]





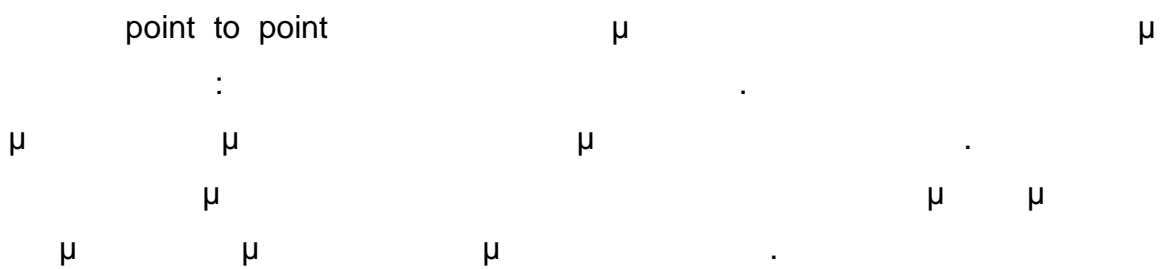
μ 3.1: Line-of-sight non-line-of-sight . [39]

3.2

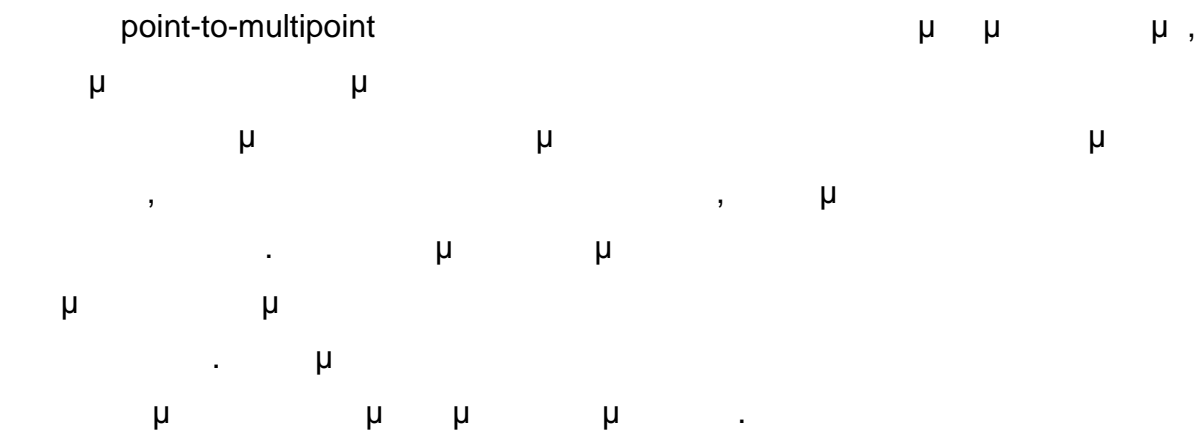
3.2.1 Point-to-point point-to-multipoint

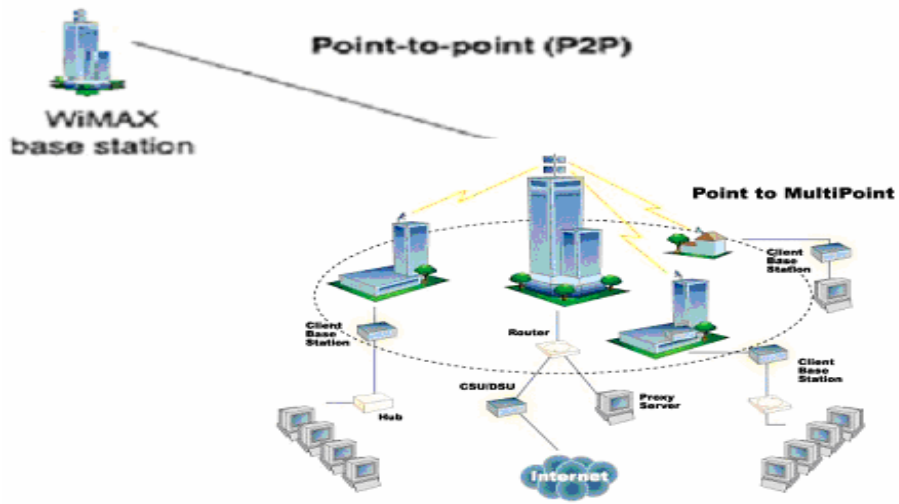
μ : point-to-point (μ) point-to-multipoint (μ μ).

Point-to-point (P2P, backhaul)



Point-to-Multipoint (PMP, last mile)





μ 3.2: Point-to-point point-to-multipoint μ . [39]

3.2.2 mesh

mesh, μ μ μ

μ μ μ (base station, BS), μ

μ mesh μ μ

μ , μ μ hops, μ

μ SS (subscriber station) mesh

μ , . . . SS μ .

mesh, μ SS μ μ

16-bit Node ID (Identifier) μ SS Mesh

BS. μ (Node ID) μ μ .

μ μ mesh MAC,

μ μ unicast.

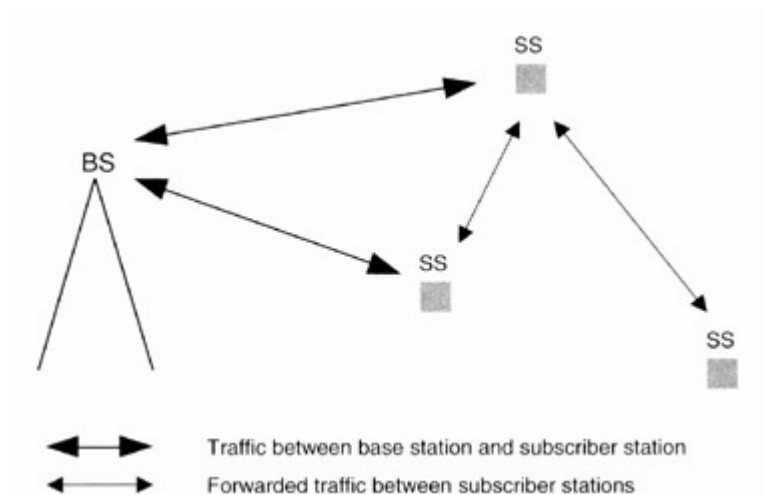
μ PMP mesh :

PMP, μ μ μ BS SSs ,

mesh μ μ μ SSs μ BS

μ SSs. PMP μ BS μ

mesh .



μ 3.3: mesh. [6]

3.3

OSI

IEEE 802.16

μ

OSI,

μ

μ

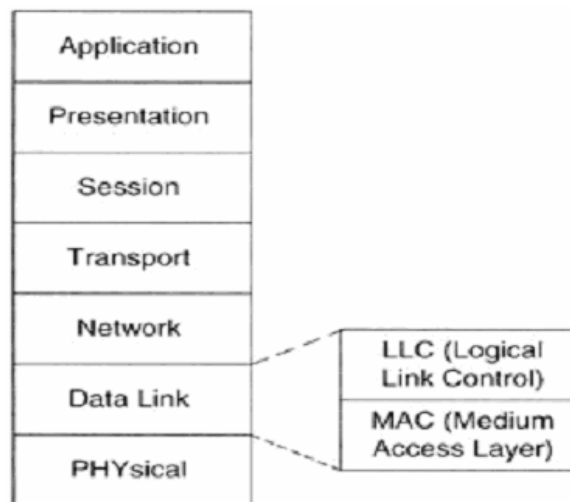
μ

OSI

μ

μ

μ



μ 3.4: 802.16, μ

. [2]

μ (PHY),
μ (Data Link). μ

[13] μ Logical Link Control (LLC) o Media Access Control (MAC).
802.16 μ μ , μ
MAC. , μ
μ μ μ
, μ μ , μ
. , μ
(QoS) μ ,
VoIP, HTTP, FTP. μ μ μ
μ μ μ μ
μ . MAC ,
, μ ,
μ .

4 - Data Link (MAC - LLC)

4.1

Data Link ()

MAC (Media Access Control) LLC (Logical Link Control).

MAC (PHY). WirelessMAN

MAC. WirelessMAN

MAC WirelessMAN

LLC interface

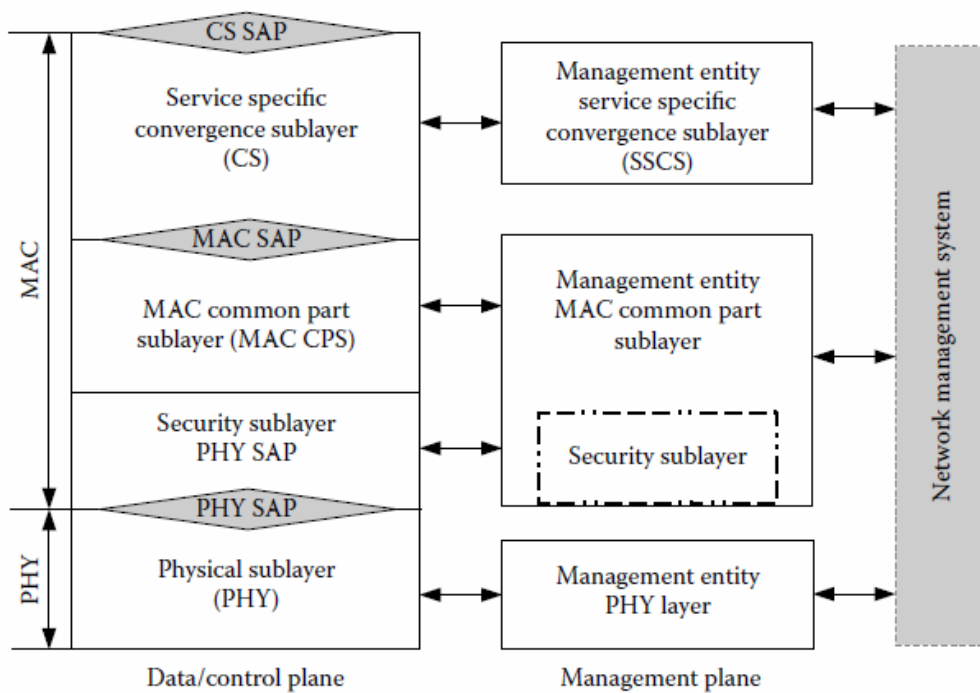
4.2

- MAC WiMax :
- SDUs MAC PDU, MAC (power level)
 - MAC PDU.
 - MAC PDUs (ARQ).

- QoS
- PDU
- MAC PDU
- power saving mode
- idle-mode

4.3 Mac

MAC, CS (Convergence Sublayer), CPS (Common Part Sublayer), Security Sublayer). [2, 4, 12]



4.1: MAC [12]

4.3.1 Convergence Sublayer (CS)

The service-specific Convergence Sublayer, CS, MAC. CS PDUs, MAC CPS, QoS WiMax/802.16, MSDUs, CIDs.

CS Payload Header
 Suppression (PHS), μ μ μ
 μ
 μ
 802.16-2004

CS.

CS CS ATM (Asynchronous Transfer Mode). CS μ (ATM) μ
 ATM μ MAC CP SAP. CS ATM
 (cells) ATM ATM, μ
 PHS. CS ATM μ CS PDUs MAC SAP.
 μ CS CS . CS
 μ μ

Internet Protocol (IP), IPv4, IPv6, Point-to-Point Protocol (PPP)

IEEE standard 802.3 (Ethernet). μ PHS

CS

4.3.2 Common Part Sublayer (CPS)

Common Part Sublayer (CPS) μ MAC .
 CPS MAC μ
 :
 • μ
 •
 • μ
 802.16-2004 μ μ
 μ . μ μ μ SS BS
 μ , μ μ μ μ
 μ
 CPS μ CSs, μ MAC SAP,
 μ MAC. QoS μ
 μ
 CPS μ :

(Device/user authentication):

WiMax
Internet Engineering Task Force (IETF) EAP,
WiMax
X.509
MAC.

Flexible key-management protocol:

Protocol Version 2 (PKMv2)
PKM
BS
X.509
(Rivest-Shamer-Adleman)
BS MS.

(Protection of control messages):

AES-based CMAC MD5-based HMAC.

(Support for fast handover):

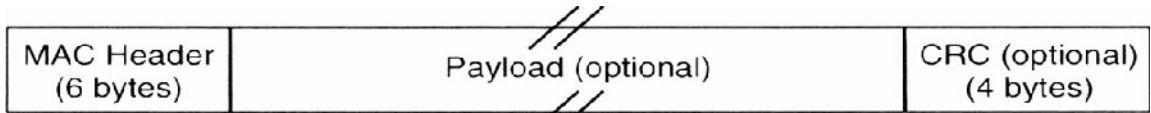
WiMax MS
BS

4.4

SS μ 48-bit MAC, IEEE 802 MAC.
 μ μ μ SS μ
 μ μ SS. μ
 BS SS
 802.16 BS 48-bit Base Station ID (BSID).
 MAC BS. μ 24-bit
 μ μ μ μ Downlink Channel
 Descriptor (DCD) MAC.
 Mesh, μ μ
 MAC, μ SS μ
 μ Identifier (Node ID) μ SS
 Mesh BS. Node ID μ μ
 Mesh mode.

4.5 MAC PDU format.

MAC PDU μ μ μ μ MAC, μ μ
 MAC. μ
 MAC PDU (MPDU) μ
 (CRC).
 μ μ MAC CS μ CS μ μ
 μ
 downlink MAC PDU μ MAC
 payload CRC.
 uplink MAC PDU MAC:
 payload μ payload CRC.
 header type (HT) μ uplink.
 HT μ μ
 payload subheader CRC payload.
 downlink MAC PDU, μ , μ
 μ μ μ μ MAC.



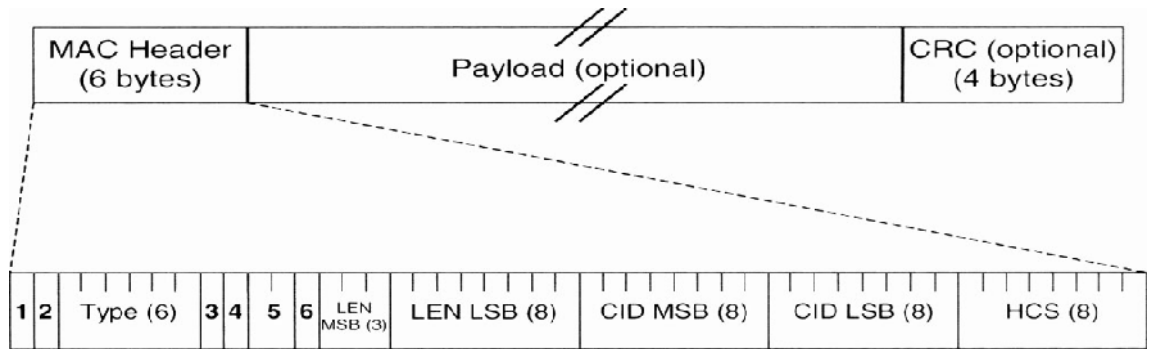
μ 4.2:

μ

MAC MAC PDU. [6]

MAC

μ



1: HT=0

2: EC

3: ESF

4: CI

5: EKS

6: Reserved

μ 4.3:

MAC. [6]

:

μ

μ

:

subheaders

μ

μ

μ

:

μ subheader

DL

UL

μ subheader

μ subheader.

μ subheader

μ

MAC.

EKS:

μ

μ

μ

μ

μ

μ subheaders.

LEN:

μ

μ

MAC

PDU, μ μ μ

CRC.

CID:

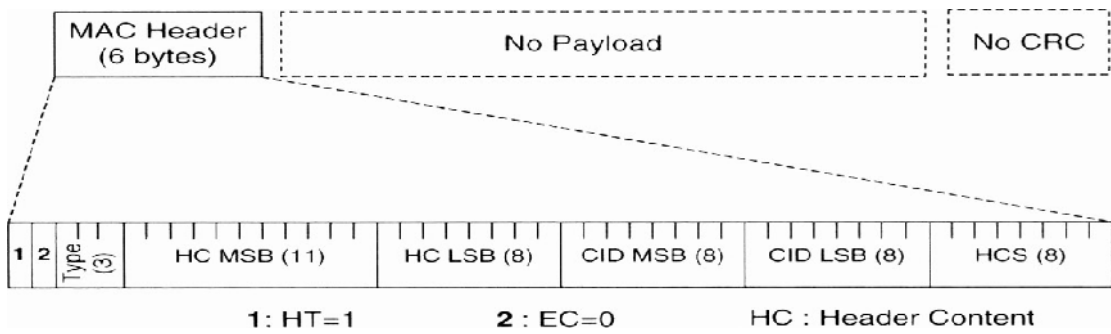
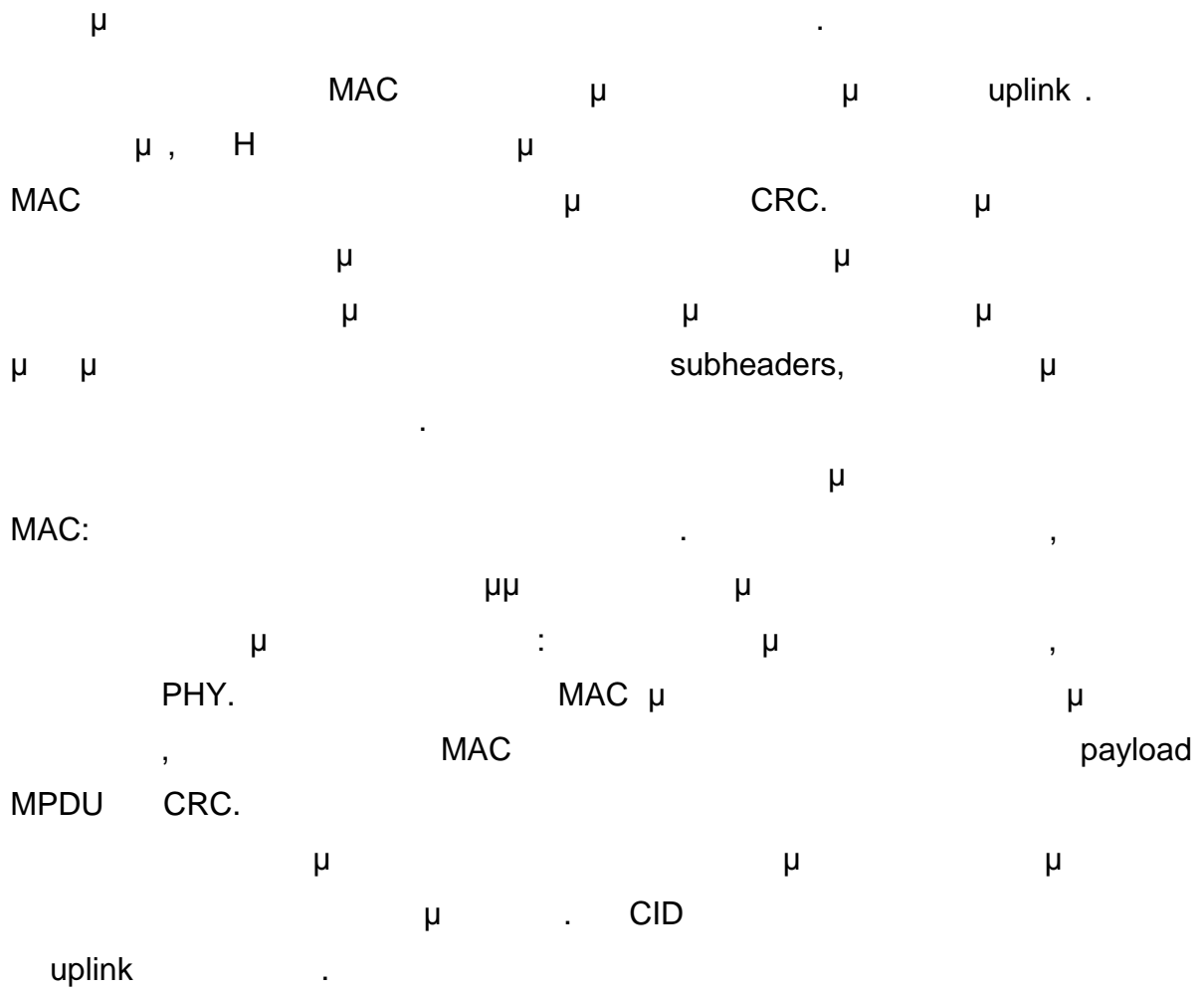
CID

μ

BS

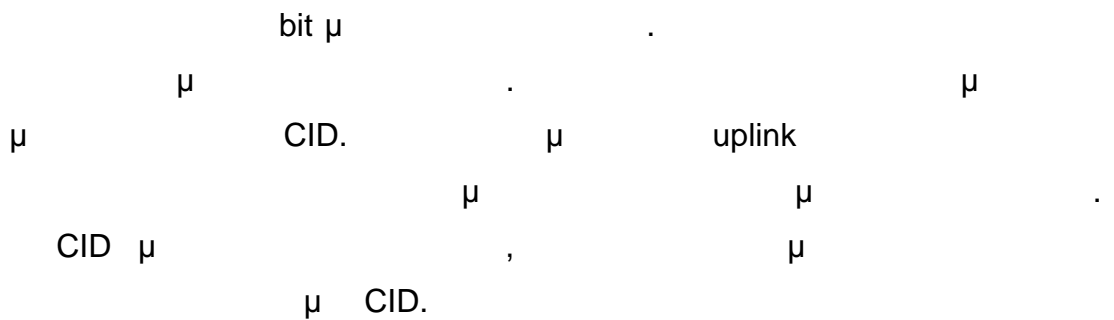
HCS:

8 bit



4.4:

payload Type I. [6]



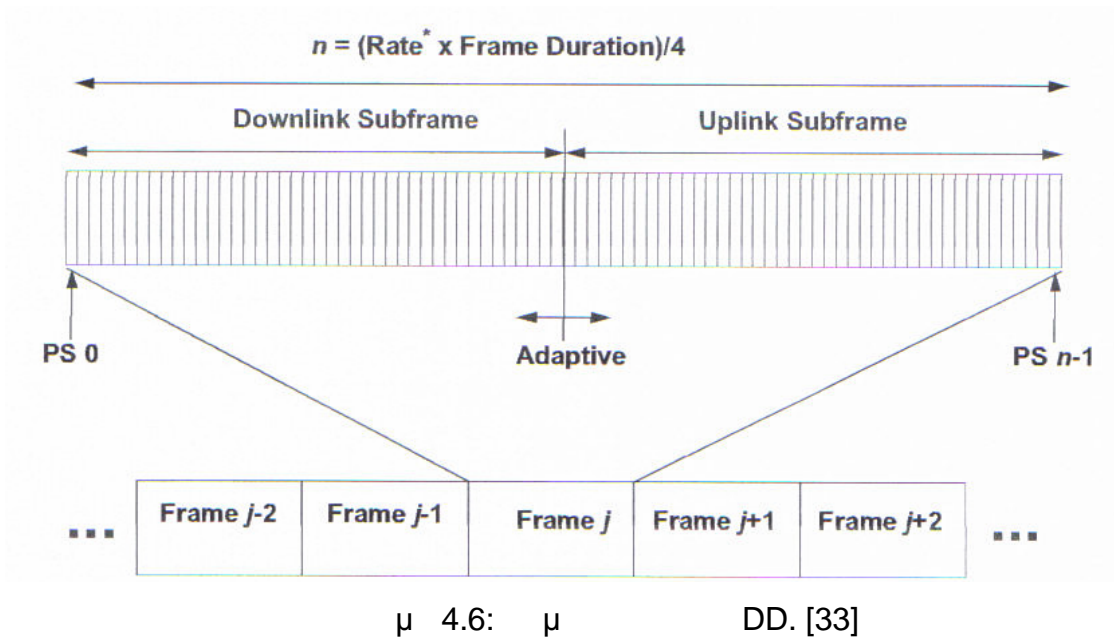
payload MAC bit. [2, 4, 6]
 MAC PDU, CID
 MAC PDU, QoS CIDs
 QoS MAC PDUs
 IDs, MAC PDUs, WiMax
 MAC PDUs,

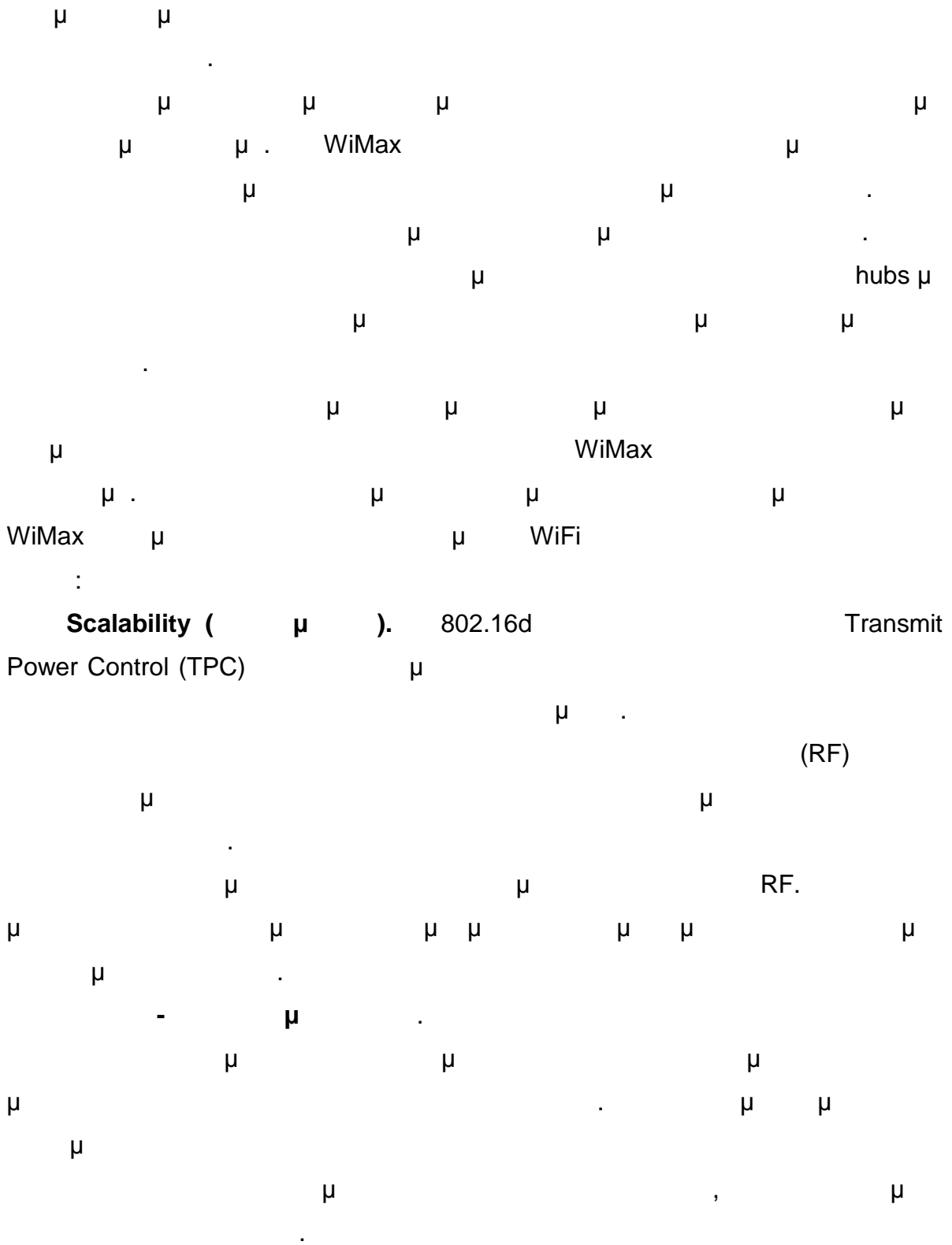
4.6 MAC PDUs

802.16 MAC
 ATM IP (Internet Protocol). MAC SDUs
 MAC PDU,
 MAC.
 MAC SDUs
 IEEE
 802.16
 IEEE

4.7 Fragmentation

Fragmentation (MAC SDU
 MAC PDUs,
 MSDU,

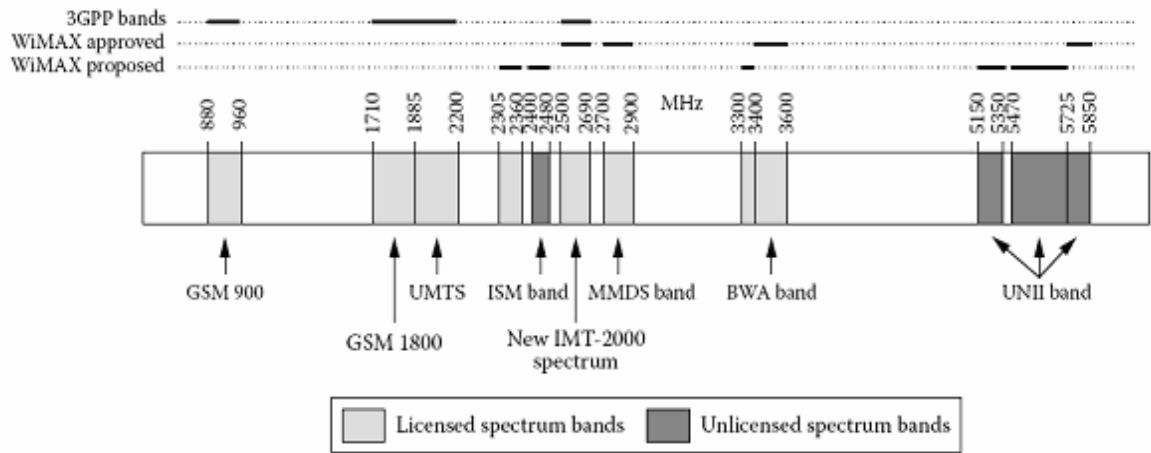




Scalability (μ). 802.16d Transmit
 Power Control (TPC) μ (RF)

5.2 WiMax
 2.3 GHz, 2.5 GHz, 3.5 GHz, 5.7 GHz
 WiMax. μ WiMax

μ



μ 5.2: μ . [41]

5.2.1 μ 2.5 GHz

μ 2.5 GHz 2.7 GHz

μ

μ

μ

μ

μ

FCC

μ

1998

μ

2004

broadband radio services (BRS)

μ

MMDS

μ

BRS

195

MHz,

μ

μ

μ

μ

μ (multi-point distribution services, MDS), μ

μ

μ

2.495 GHz

2.690 GHz.

μ

μ

μ

μ

μ

μ

FDD

TDD.

22.5 MHz

μ μ

μ

16.5 MHz

μ

μ

6 MHz, μ

μ

μ

μ

10 MHz

55

MHz.

μ

(

μ

μ

μ

Sprint, Nextel,

Clearwire.

μ

μ

μ

WiMax.

5.2.2

μ 2.3GHz

WCS μ ,

μ ,

μ , WiBro

μ ,

μ μ 5MHz μ 5

MHz 2.305 GHz 2.320 GHz 2.345 GHz 2.360 GHz.

μ μ

μ μ

FCC

DARS (, 2.320 GHz 2.345 GHz).

μ μ

DARS.

5.2.3

μ 3.5GHz

μ

accessseveral , μ μ

μ , FCC

50MHz μ 3.65 GHz μ 3.70 GHz

μ GHz

μ 3.4 GHz 3.6 GHz, μ

μ 3.3 GHz 3.4 GHz 3.6 GHz 3.8 GHz . μ

200MHz.

μ μ μ ,

2x5 MHz 2x56 MHz.

μ μ FDD ,

FDD TDD.

μ μ . μ

μ μ

μ WiMax μ μ μ

μ

3.5 GHz,

μ .

5.2.4

μ 5GHz

μ μ 5.25GHz 5.85GHz
 WiMax. μ μ ,
 μ μ μ μ (national
 information infrastructure, U-NII) 200MHz μ
 . 255MHz μ
 FCC μ μ μ .
 μ μ , μ μ
 WiMax, μ μ μ
 μ . μ μ μ
 μ μ
 μ μ μ μ
 μ , μ . , μ
 μ μ μ μ
 μ , μ , .
 5 GHz, μ 5.725 GHz μ 5.850
 GHz WiMax. μ
 80 MHz μ μ μ , 2.4 GHz,
 μ μ μ WiMax. μ
 , Wi-Fi,
 WiMax 2.4 GHz , point-to-multipoint
 μ .
 2.3 GHz, 2.5 GHz, 3.5 GHz, 5.7 GHz
 WiMax, μ μ
 WiMax. μ UHF (
) AWS.

5.3 UHF bands

μ , μ μ
 , μ μ μ μ 800
 MHz. μ , μ , FCC
 698 MHz-746 MHz μ μ μ
 TV. 18 MHz μ
 μ , μ 60 MHz μ μ μ

. μ μ TV
 μ μ μ
 2010. FCC
 μ 700MHz,
 μ μ . UHF μ
 μ μ μ
 μ μ μ ,
 . μ μ
 μ .

5.4 AWS band

2006, FCC μ 1.710 GHz-1.755 GHz
 μ 2.110 GHz-2.155 GHz μ μ μ
 (advanced wireless services, AWS) μ .
 90 MHz μ μ
 μ .

5.5

, WiMax μ
 3G. , 3G μ
 WiMax .
 L-band 1.5GHz μ
 μ μ μ
 μ μ μ , μ
 μ μ μ : 6 GHz, 11 GHz, 18 GHz 23 GHz. [1,
 4, 10, 25]

Designation	Frequency Allocation	Amount of Spectrum	Notes
Fixed wireless access (FWA): 3.5GHz	3.4GHz – 3.6GHz mostly; 3.3GHz – 3.4GHz and 3.6GHz – 3.8GHz also available in some countries	Total 200MHz mostly; varies from 2 × 5MHz to 2 × 56MHz paired across nations	Not generally available in the United States. A 50MHz chunk from 3.65GHz – 3.70GHz being allocated for unlicensed operation in United States.
Broadband radio services (BRS): 2.5GHz	2.495GHz – 2.690GHz	194MHz total; 22.5MHz licenses, where a 16.5MHz is paired with 6MHz	Allocation shown is for United States after the recent change in band plan. Available in a few other countries as well.
Wireless Communications Services (WCS) 2.3GHz	2.305GHz–2.320GHz; 2.345GHz – 2.360GHz	Two 2 × 5MHz paired; two unpaired 5MHz	Allocation shown for United States. Also available in Korea, Australia, New Zealand.
License exempt: 2.4GHz	2.405GHz – 2.4835GHz	One 80MHz block	Allocation shown for United States but available worldwide. Heavily crowded band; used by Wi-Fi.
License exempt: 5GHz	5.250GHz–5.350GHz; 5.725GHz – 5.825GHz	200MHz available in United States; additional 255MHz to be allocated	Called U-NII in United States. Generally available worldwide; lower bands have severe power restrictions.
UHF band: 700MHz	698MHz – 746MHz (lower); 747MHz – 792MHz (upper)	30MHz upper band; 48MHz lower band	Allocations shown for United States, only 18MHz of lower band auctioned so far. Other nations may follow.
Advanced wireless services (AWS)	1.710GHz–1.755GHz 2.110GHz – 2.155GHz	2 × 45MHz paired	Auctioned in the United States. In other parts of the world, this is used for 3G.

μ 5.3:

μ

WiMax. [4]

6 -

(PHYSICAL)

6.1

WiMax μ BWA (Broadband Wireless Access),
 μ () μ
 μ μ μ μ .
 μ (uplink downlink). μ 802.16
 μ bit. μ μ μ
 μ μ μ μ
 .
 802.16 μ o 2-66 GHz .
 μ :
 • μ 2 11 GHz NLOS
 μ .
 • μ 10 66 GHz μ
 LOS.
 (air interfaces) 802.16
 :
 • WirelessMAN-SC 10-66GHz
 • WirelessMAN-SCa μ <11GHz
 • WirelessMAN-OFDM μ <11GHz
 • WirelessMAN-OFDMA μ <11GHz
 • Wireless HUMAN μ μ <11GHz
 μ ,
 μ duplexing μ , MAC.

Designation	Frequency band	Duplexing	MAC options
WirelessMAN-SC (known as SC)	10–66 GHz (LOS)	TDD and FDD	
WirelessMAN-SC (known as SCa)	Below 11 GHz (NLOS); licensed	TDD and FDD	AAS, ARQ, STC mobility
WirelessMAN-OFDM (known as DFDM)	Below 11 GHz; licensed	TDD and FDD	AAS, ARQ, STC, mesh mobility
WirelessMAN-OFDMA (known as DFDMA)	Below 11 GHz; licensed	TDD and FDD	AAS, ARQ, HARQ, STC mobility
WirelessHUMAN	Below 11 GHz; license exempt	TDD only	AAS, ARQ, STC mesh

6.1: . [6]

6.2 10-66 GHz

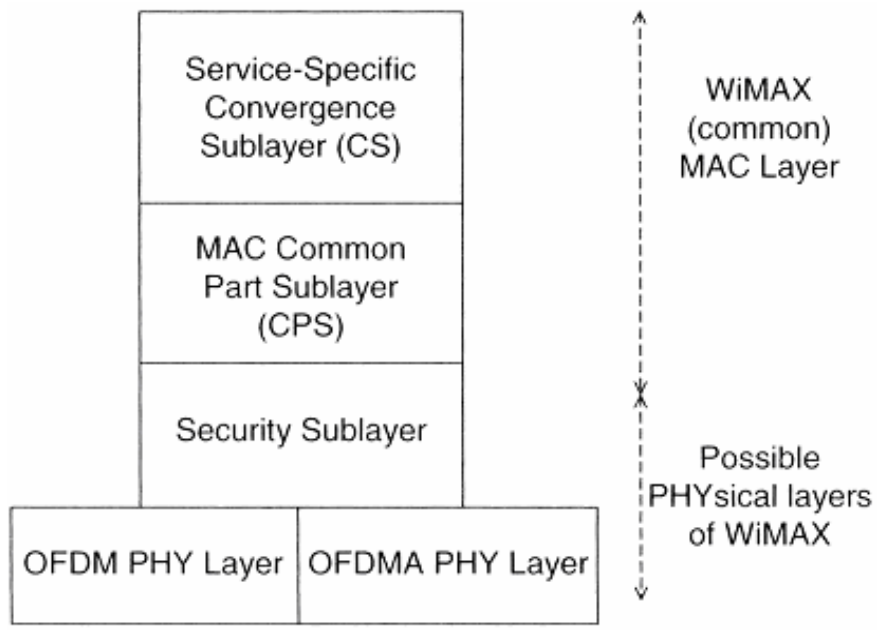
WirelessMAN-SC: 10-66 GHz, LOS, μ , μ , μ point-to-multipoint, BS, μ TDM (Time Division Multiplexing), μ μ μ (time slot). uplink μ TDMA (Time Division Multiple Access) μ μ μ μ μ TDD (Time Division Duplexing), uplink downlink μ μ FCC (Frequency Division Duplexing), uplink downlink half-duplex FDD subscriber stations, μ μ μ

6.3 2–11 GHz

- 2-11 GHz bands, μ μ .
 μ , μ
 μ . 2-11 GHz
 μ non-line-of-sight (NLOS) .
 μ μ , μ
 μ μ BS. μ ,
 μ . , μ
 μ . 2-11 GHz
 :
- WirelessMAN-SCa, SCa μ μ
 μ .
 - WirelessMAN-OFDM, OFDM (Orthogonal Frequency-Division
 Multiplexing) μ NLOS
 11 GHz.
 μ μ OFDM μ ,
 μ - (subcarriers), o μ
 μ FFT μ .
 - WirelessMAN-OFDMA, OFDMA (Orthogonal Frequency
 Division Multiple Access), μ 802.16e .
 NLOS
 11 GHz. μ , μ
 μ
 μ μ μ 2,
 1.0 z. OFDM μ -
 (subcarriers), o μ μ FFT
 μ .
 - Wireless HUMAN (High-speed Unlicensed Metropolitan Area Network),
 μ μ
 μ μ μ (Dynamic Frequency
 Selection, DFS)
 μ μ
 μ , μ μ μ μ

6.4

WiMax OFDM
 WiMax, OFDMA
 ()

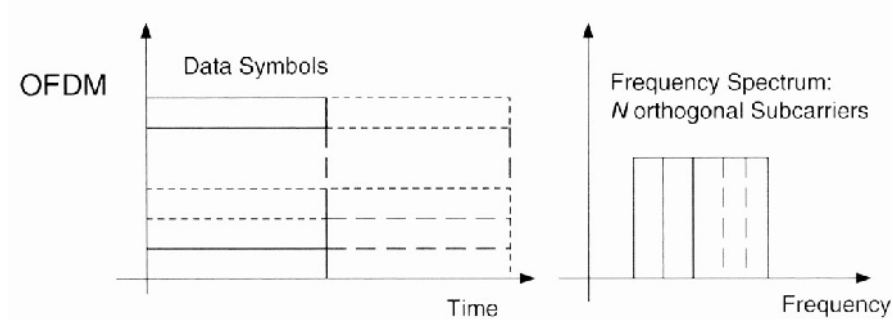
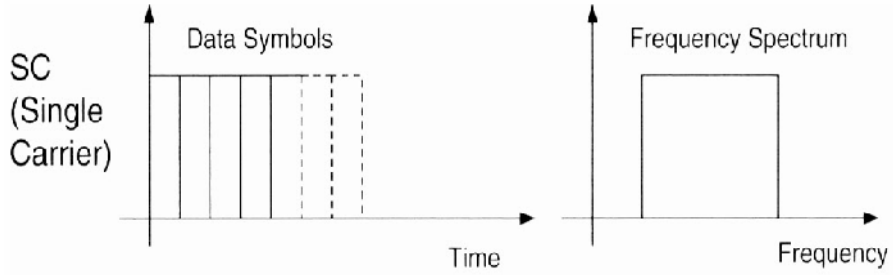


6.1: MAC . [6]

6.4.1 OFDM

OFDM (subcarriers).
 OFDM (subcarriers).
 OFDM (subcarriers).

SC). , OFDM (Single Carrier, OFDM)



6.2: SC OFDM. [6]

(SC). OFDM

6.4.2 H (Single Carrier, SC) OFDM

OFDM

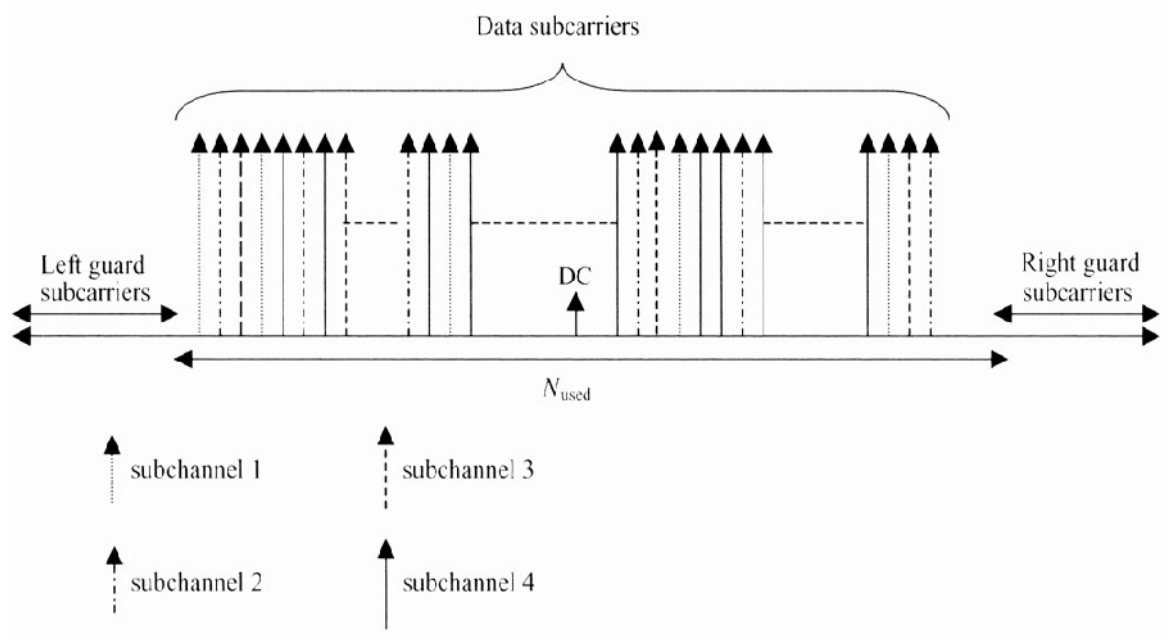
(SC).

OFDM

μ 3,5-5 b/s Hz μ
 μ μ CDMA (Code Division Multiple Access)
 μ 3G,
 μ

6.4.3 OFDMA

μ OFDM μ μ
 μ , μ μ OFDM TDMA
 FDMA. μ , μ OFDM μ
 μ , OFDM
 OFDMA, μ (subcarriers) OFDMA
 (subsets) μ ,
 subchannel. downlink, subchannel μ
 μ , uplink μ
 μ μ subchannels.
 μ OFDM subchannels
 μ , μ
 OFDMA. downlink uplink μ μ μ
 subchannel μ



μ 6.3: OFDMA. [6]

6.4.4 OFDMA (Scalable OFDMA, SOFDMA)

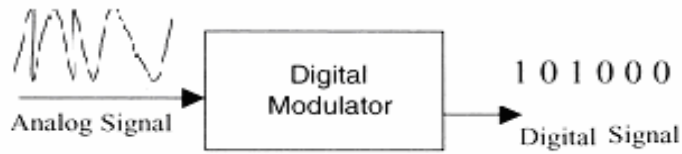
PHY. OFDMA PHY Scalable OFDMA (SOFDMA). OFDM ,

FFT 2048, 1024, 512 128. 1024 512

WiMax.

6.5

WiMax/802.16



6.4: [6]

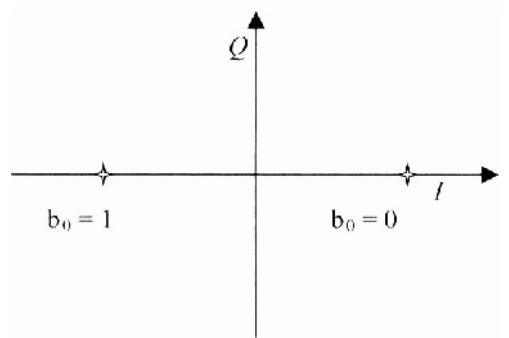
IEEE 802.16 : BPSK, QPSK, 16-QAM 64-QAM.

6.5.1 BPSK (Binary Phase Shift Keying, BPSK)

BPSK bit.

bits:

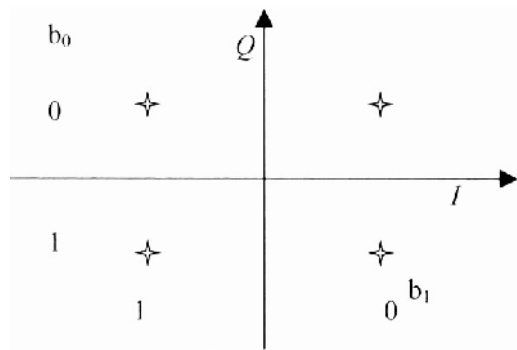
BPSK



6.5: binary phase shift keying . [6]

6.5.2 (Quadrature Phase Shift Keying, QPSK)

QPSK



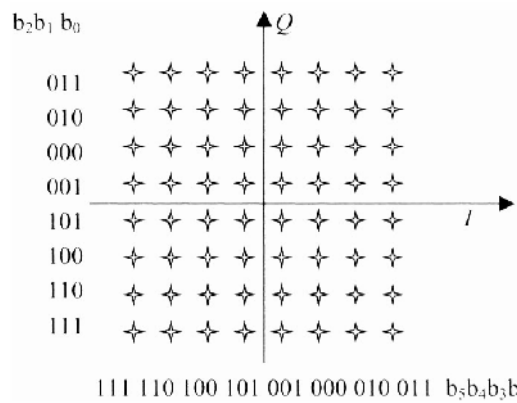
6.6: . [6]

6.5.3 (Quadrature Amplitude Modulation, QAM): 16-QAM 64-QAM

QAM

16-QAM (4 bits/) 64-QAM (6 bits/)

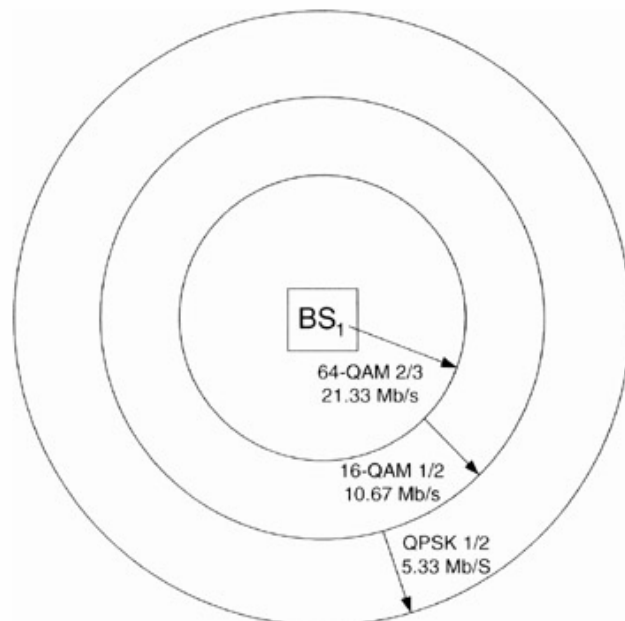
IEEE 802.16, 64-QAM, 6 bits



6.7: 64-QAM . [6]

6.5.4

GSM//EDGE, UMTS, WiFi). SS BS.



6.8: . [6]

6.6

(chains) μ

WiMax

μ

WiMax

OFDM

OFDMA PHYs.

6.6.1

μ

PHY OFDM

OFDMA

blocks

μ

OFDMA PHY

μ

block.

μ

μ

μ

μ

: BPSK, QPSK, 16-QAM

64-QAM.

μ

μ

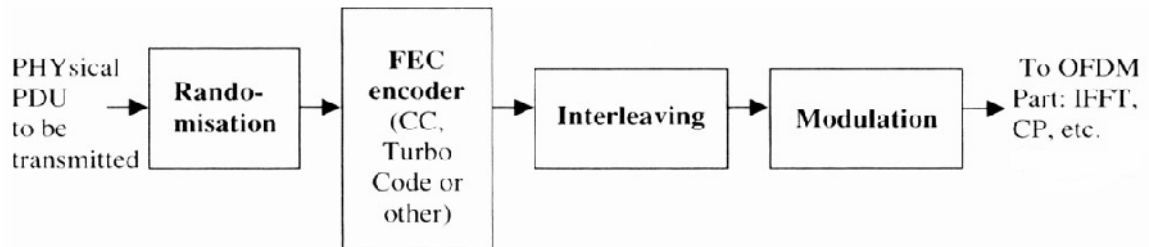
μ

μ

OFDM.

μ

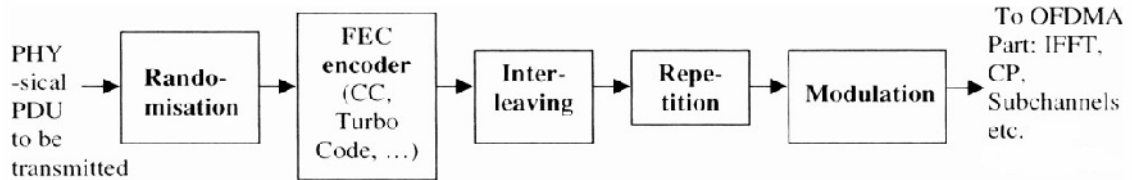
μ



μ 6.9:

μ

OFDM PHY. [6]



μ 6.10:

μ

OFDMA PHY. [6]

6.6.2

μ

μ

μ

μ

μ

μ

μ

μ

,

μ

μ

μ

. 802.16

μ : randomisation, Forward Error Correction

(FEC)

interleaving

μ

μ

.

μ HCS CRC.

6.6.3 Randomisation

Randomisation μ « » «μ ».

downlink uplink .

μ μ ,

block 0xFF («ones» μ) μ .

Pseudo-Random Binary Sequence (PRBS)

μ randomisation μ .

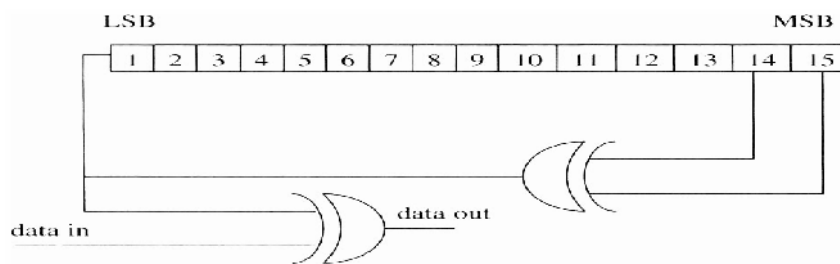
byte μ , randomiser,

μ byte (Most Significant Byte, MSB). randomiser

μ μ bits . preambles

bits randomiser μ

FEC.



μ 6.11: PRBS. [33]

6.6.4 Forward Error Correction (FEC)

OFDM PHY, FEC :

- Concatenated Reed-Solomon Convolutional Code (RS-CC).
uplink downlink.
- Reed-Solomon
- Convolutional Turbo Codes (CTC) ().
- Block Turbo Coding (BTC) ().

μ

OFDMA PHY,

FEC :

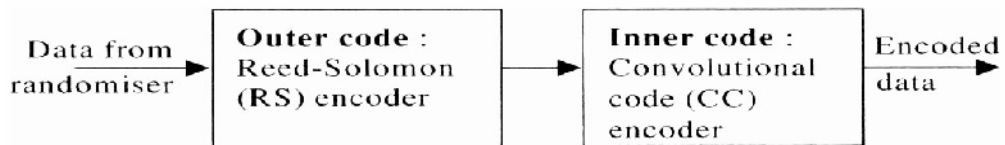
- (Tail-biting) Convolutional Code (CC). μ μ WiMax, μ Zero-Tailing Convolutional Code (ZT CC) μ .
- Convolutional Turbo Codes (CTC). μ μ 802.16 , μ μ WiMax , CTC .
- Block Turbo Coding (BTC) () .
- Low Density Parity Check (LDPC) () .

6.6.4.1 RS-CC (Reed–Solomon Convolution Code)

OFDM PHY,

RS-CC

Code (CC) μ RS μ Convolutional Code (CC) μ Reed-Solomon μ μ RS μ bits μ μ μ μ () μ μ μ μ .



µ 6.12: . [6]

6.6.4.2 Turbo codes

Turbo FEC Shannon μ μ μ turbo FEC interleaver. μ .

turbo . μ μ μ μ

μ μ turbo

6.6.4.3 Convolutional Turbo Codes (CTC)

Convolutional Turbo Codes (CTC) optional FEC

OFDM OFDMA PHY. OFDMA PHY, CTC μ μ

optional Hybrid ARQ (HARQ). μ μ mobile

WiMax , CTC OFDMA PHY. μ

μ μ subchannels

μ μ subchannels μ μ

μ μ , μ μ

μ μ μ HARQ.

6.6.4.4 Block Turbo Codes (BTC)

block Turbo Codes (BTC) FEC OFDM

OFDMA PHY. OFDM OFDMA PHY, BTC μ μ

Hamming .

6.6.4.5 (Tail-biting) Convolutional Code (CC)

tail-biting convolutional OFDMA (CC)

: convolutional μ μ μ ()

bits μ FEC (bits

μ bn, 5,...,bn)). convolutional OFDMA

PHY μ Zero-Tailing Convolutional

Coding (ZT CC). , μ 0 * 00 tail byte

tail. tail byte μ randomisation.

6.6.5 Interleaving

Interleaving (μ) μ ,
 μ μ μ ,
 μ . μ
 bits μ . μ
 interleaver μ :

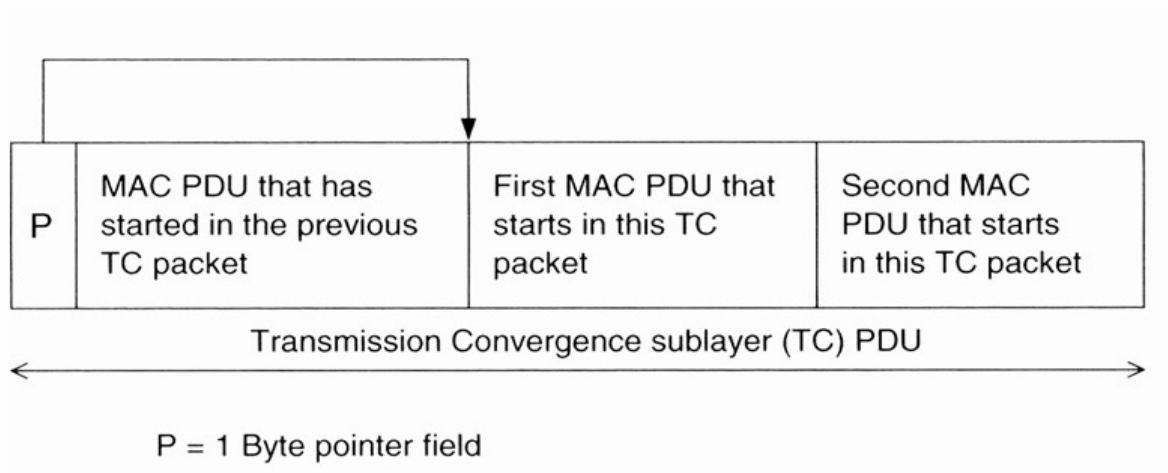
- μ μ bits μ .
 μ bits
- nonadjacent μ .
 μ bits
 μ bits
- constellation,
 bits μ .

6.6.6 Repetition

(Repetition) 16e OFDMA PHY.
 μ μ
 μ μ μ μ FEC.
 μ μ QPSK.
 μ HARQ μ CTC.

6.7 Transmission Convergence Sublayer (TCS)

TCS μ μ MAC PHY.
 TCS, μ MAC PDUs μ μ μ
 FEC μ , μ TC PDU. byte
 TC PDU. MAC PDU.
 TCS μ μ OFDM PHY
 μ μ OFDMA PHY. uplink
 downlink.



6.13: downlink Transmission Convergence PDU. [6]

6.8 Duplexing

WiMax/802.16 duplexing :
 Time Division Duplexing (TDD) Frequency Division Duplexing (FDD).

duplexing μ μ μ μ

6.8.1 FDD

μ FDD, uplink downlink μ

uplink downlink μ

μ full-duplex SSs, μ, half-duplex SSs. full-duplex SS μ

μ downlink, half-duplex SS μ μ

μ downlink μ uplink

μ half-duplex SS, uplink

μ half-duplex SS μ μ

μ downlink

6.8.2 TDD

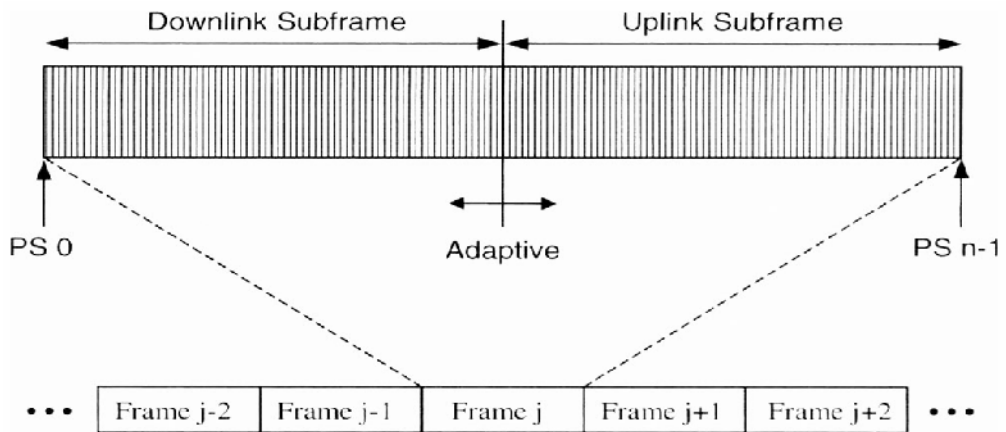
TDD, uplink downlink μ μ

μ TDD

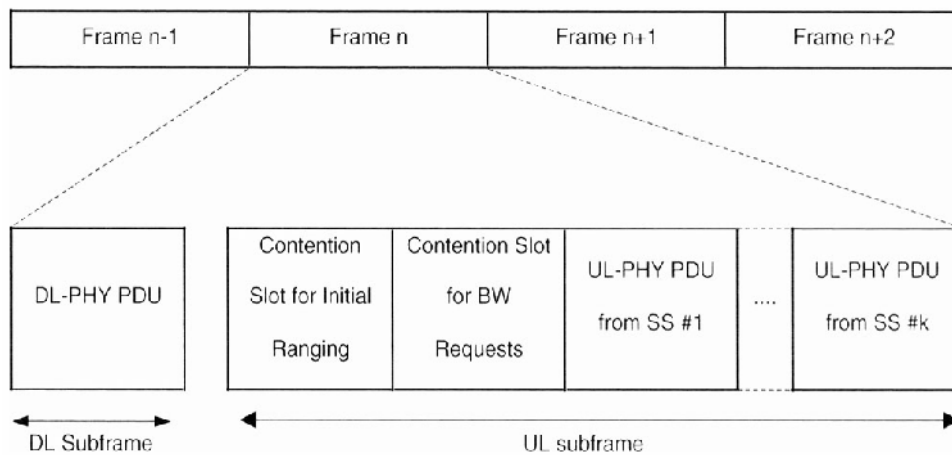
μ downlink uplink subframe.

μ μ (Physical

Slots, PSs),
 OFDM OFDMA PHYSical, PS
 TDD
 downlink uplink
 downlink uplink
 802.16



6.14: TDD frame. [6]



6.15: TDD (OFDM PHY). [6]

6.8.3 Mesh - PMP

uplink downlink
 TDD FDD TDD
 (uplink downlink),
 Mesh TDD PMP
 duplexing TDD FDD. [6, 7]

7 -

7.1

μ WiMax, Wi-Fi,



μ
μ
μ
, μ

μ μ μ ,

« »

μ μ

μ μ

μ , μ μ μ .

μ μ

μ μ μ

μ

μ μ

μ μ μ

IP.

Layer	Security Mechanism	Notes
Link	AES encryption, device authentication, port authentication (802.1X)	Typically done only on wireless links
Network	Firewall, IPsec, AAA infrastructure (RADIUS, DIAMETER)	Protects the network and the information going across it
Transport	Transport-layer security (TLS)	Provides secure transport-layer services, using certificate architecture
Application	Digital signatures, certificates, secure electronic transactions (SET), digital rights management (DRM)	Can provide both privacy and authentication; relies mostly on public key infrastructure

7.1: μ μ

IP. [1]

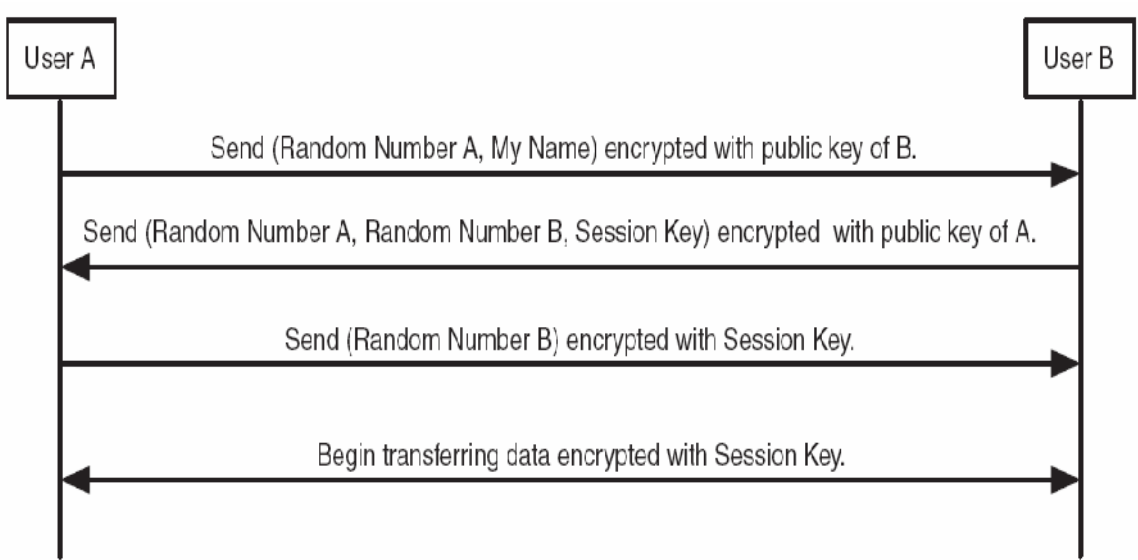
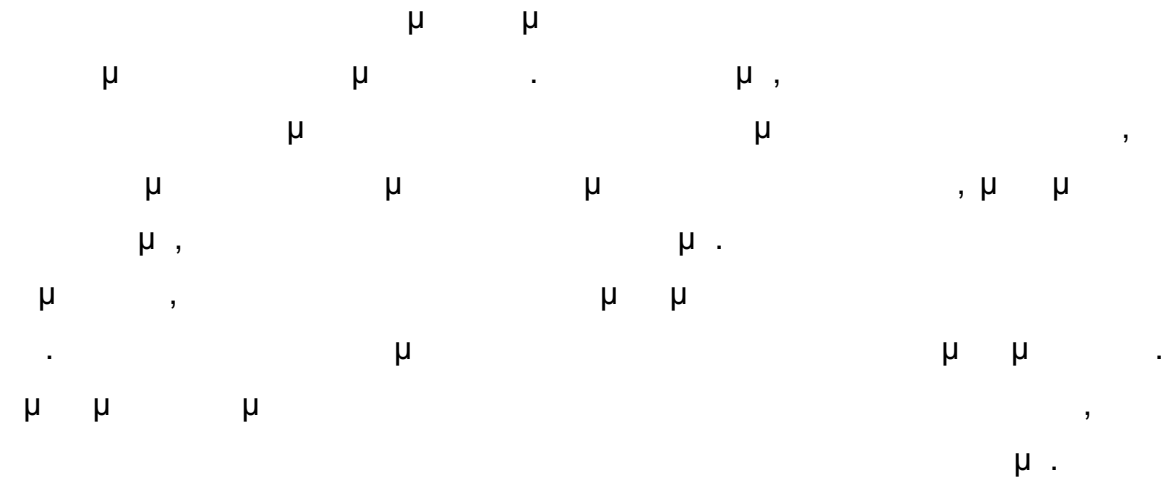
IPsec, firewalls, AAA (authentication, authorization, and accounting), and RADIUS (Remote Access Dial-In User Service).

IEEE 802.16e (802.16-2004) (BS)

7.2

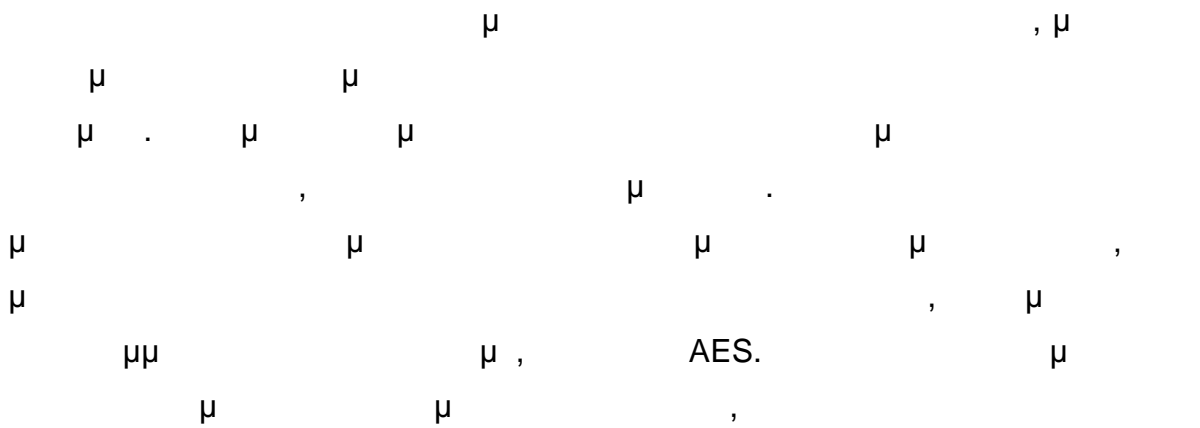
- **(Authentication):**
- **(Privacy):**
- **(Data integrity):**
- **(Authorization):**
- **(Access control):**

7.2.1



7.1: PKI. [30]

7.2.2



7.2.3

μ μ
 ο PKI μ μ
 « ».
 μ μ . μ ,
 μ , μ
 .
 μ , μ
 μ μ « »
 « » ,
 μ .
 μ μ « » ,
 μ 128-bit μ μ . MD-5 SHA
 μ μ μ μ μ μ
 μ .

7.2.4

μ . μ μ μ μ , μ
 , VeriSign,
 μ PKI
 .
 μ , μ μ μ .
 μ . μ
 μ μ . μ
 μ μ μ μ μ μ μ
 μ μ μ μ μ μ
 .

7.2.5

μ μ
 μ . ,
 μ :
 • μ : supplicant
 • μ : authenticator

- μ supplicant :
 .
 μ dial-
 up modems μ .
 dial-up services PPP (point-to-point
 protocol) RADIUS.
 PPP μ μ supplicant authenticator,
 router network access server (NAS),
 RADIUS μ μ authenticator
 .
 PPP μ : PAP
 (password authentication protocol) CHAP (challenge handshake authentication
 protocol) μ μ
 μ . μ μ
 EAP (extensible authentication protocol).

7.3

μ μ μ μ 802.16
 μ . μ
 μ μ μ
 μ μ μ μ
 802.16 :

- RSA (Rivest Shamir Adleman). RSA μ
 μμ μ μ
 μ μ μ (Authorisation
 Reply, AR) μ μ SS. AR μ
 μ (Authorisation Key, AK). RSA μ
 μ μ BS
 SS.

- DES (Data Encryption Standard). DES 3-DES
 μ . μ DES μ
 μ μ μ

802.16

μ 3-DES μ

μ

μ

μ

Triple-DES,

μ

μ

, μ

- AES (Advanced Encryption Standard).

μ AES

μ

μ

μ

μ

μ

μ

μ

μ

μ

802.16

- HMAC (Hashed Message Authentication Code)

CMAC (Cipher-based

Message Authentication Code). HMAC

CMAC

μ

μ

μ

7.4

μ

μ

μ

μ

μ

μ

μ

μ

μ

stream

block

μ

,

μ «plaintext»,

μ

stream

block

μ

«encryption key»,

μ

μ

μ

μ

μ

μ

«ciphertext».

μ

μ

μ

μ

μ

«decryption»

plaintext

μ

μ

μ

,

μ

μ

,

μμ

μ

«

μ

»

μ

μ

,

64 bytes.

μ

,

μμ

μμ

μμ

μ

μ

μ

,

7.5 Public Key Infrastructure (PKI)

Public Key Infrastructure (PKI) is a framework of hardware, software, policies, and procedures needed to create, manage, distribute, use, store, and revoke digital certificates and to authenticate the users and devices relying on the certificates. It is used to establish trust between communicating parties in a network. PKI is based on asymmetric cryptography, where a pair of keys is used: a public key and a private key. The public key is used for encryption and the private key is used for decryption. PKI is used in various applications, including secure email, secure web browsing, and secure network communications.

7.6 Advanced Encryption Standard (AES)

The Advanced Encryption Standard (AES) is a symmetric-key algorithm for the encryption of digital data. It was selected by the National Institute of Standards and Technology (NIST) in 2001 to replace the Data Encryption Standard (DES). AES is based on the Rijndael cipher, which was designed by Joan Daemen and Vincent Rijmen. AES is a block cipher, meaning it encrypts data in fixed-size blocks. The most common block size is 128 bits, and the most common key size is 128 bits. AES is used in a wide variety of applications, including secure web browsing, secure email, and secure network communications.

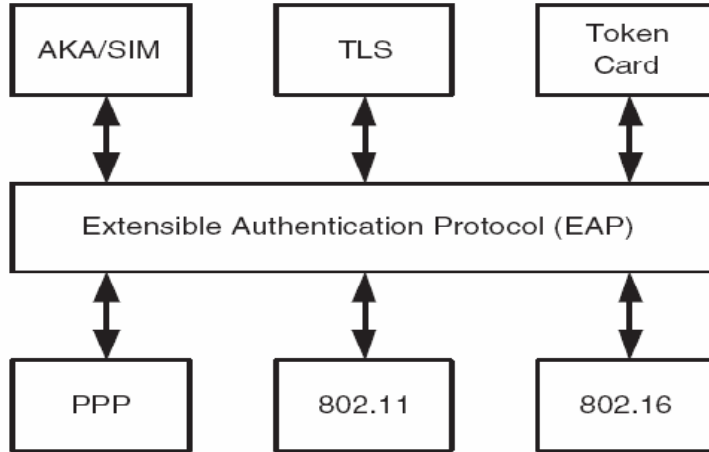
128-bit, 192-bit, 256-bit, WiMax

7.7 Privacy Key Management (PKM)

PKM, PKMv1, 802.16-2004, BS, SS, PKM

7.8 Extensible Authentication Protocol (EAP)

EAP, IETF (RFC 3748), supplicant, PPP, WiMax.



7.2:

[27]

EAP, authenticator, (negotiating)

EAP ,

μ ,

, tokens, . μ , protected EAP

(PEAP) μ EAP μ , EAP-

transport-layer security (EAP-TLS) μ

μ EAP, EAP-SIM (subscriber identity module) μ

μ SIM μ EAP. EAP-TLS μ

.

WiMax μ , EAP « » MS BS

PKMv2 (Privacy Key Management)

IEEE 802.16e-2005 air-interface. authenticator BS, BS

μ authenticator,

(access service network, ASN). authenticator

, EAP μ μ RADIUS. [4, 6]

μ , , μ μ ,
μ , , μ ,
μ , , μ ,
μ , μ ,
μ .

8.3

μ μ μ μ μ μ
μ . μ μ μ ,
μ μ μ μ .
μ μ μ , μ μ μ .

DNA, μ
μ

DNA.
μ μ μ μ μ
DNA. μ

μ μ μ μ μ
μ μ μ μ μ
μ . μ μ μ
μ .

μ , μ .
μ ,
μ .

μ
:

- μ : μ μ
(, ,), μ μ
μ «μ », μ μ
μ . , (. .)
μ μ , μ μ
, μ « ».

8.4 FCC (Federal Communications Commission)



8.5

Institute 40.581 1950 1954. National Cancer 40

40 35%

40

Specific Absorption Rate (SAR), μ

FCC

μ , μ μ
μ :

Ισχύς (W)	Επικίνδυνη Απόσταση (m)	Απόσταση Ασφαλείας (m)
1	0.2	0.3
4	0.2	0.6
10	0.3	0.95
40	0.6	2.0
400	1.9	6.0
1000	3.0	9.5

8.1: μ μ . [14]

μ , μ μ :

• μ WiFi, EIRP μ 100

mW, 0,1 Watt 10 cm

• GSM μ 1 μ 2 Watt (μ μ
) , 30 cm

• 40 Watt

, μ 10 db, EIRP=400 Watt,

6 μ

• μ μ 30000 Watt

30 μ

μ μ μ μ μ μ

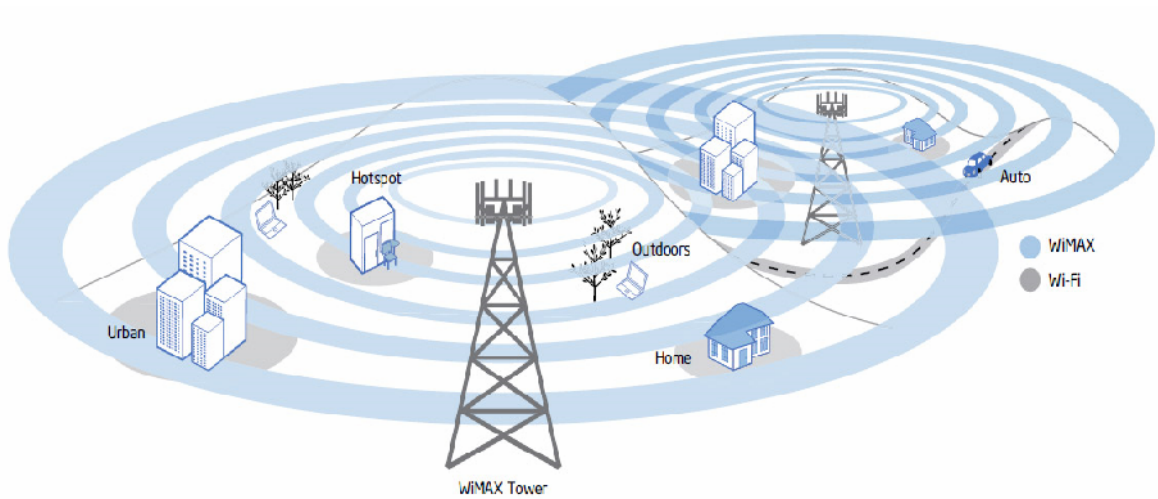
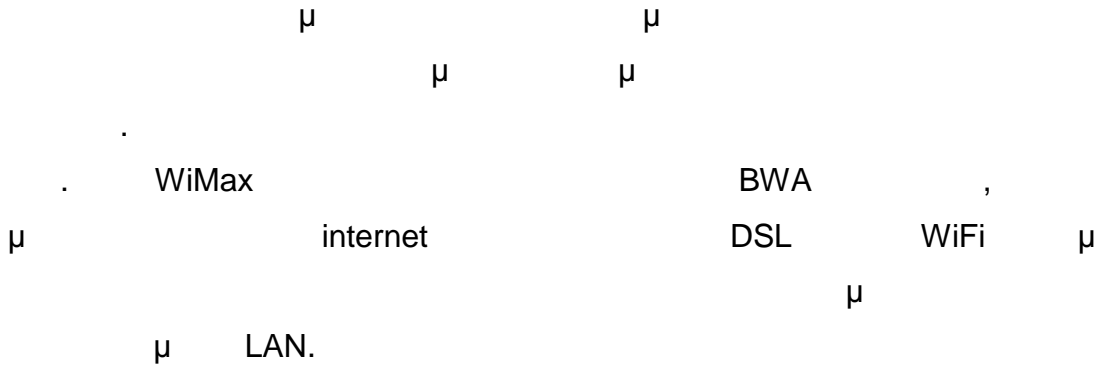
μ μ 0,1 Watt, μ μ μ
40 Watt, μ 10 cm μ 6 μ .

μ μ , μ μ μ μ μ μ
μ , μ μ 1 kW μ μ ,

μ μ μ μ 100 mW.

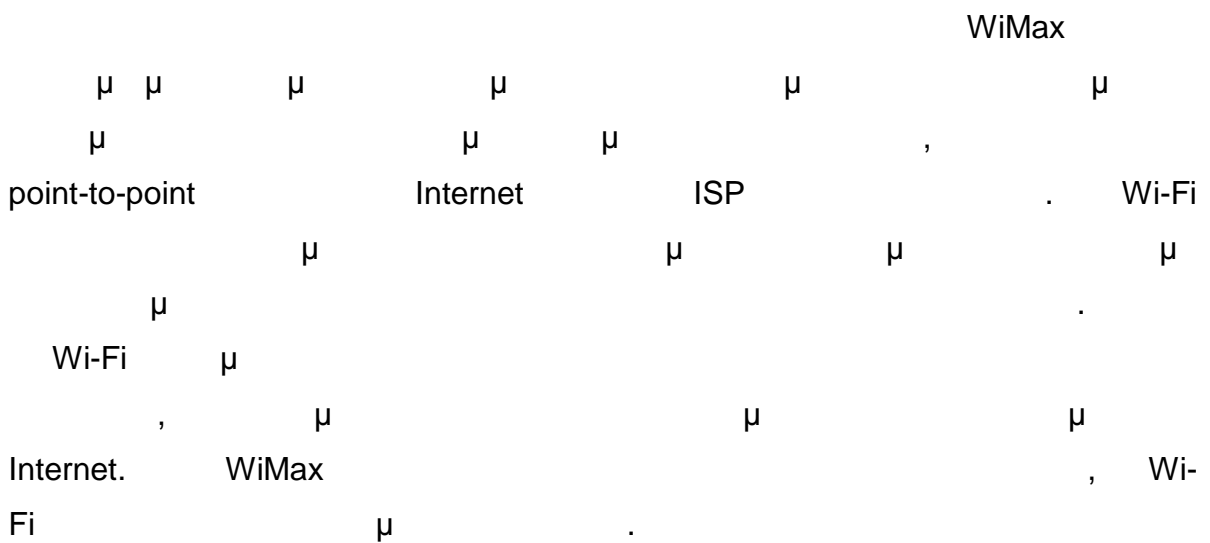
9 – WiMax – Wi-Fi

9.1



9.1 WiMax μ Wi-Fi. [39]

9.2 μ



9.3 MAC

WiMax MAC « »

802.11. Wi-Fi, MAC μ « »

μ μ μ μ μ μ

μ (AP), .

μ μ μ AP

μ μ μ , μ

μ . , 802.16 MAC μ μ

μ μ μ ,

μ . , μ ο μ μ μ .

To μ ο μ μ μ μ μ μ

μ , μ μ μ μ

μ μ μ . μ μ

μ μ μ μ μ μ

(802.11).

μ μ

, μ μ

μ μ .

9.4

WiMax

μ Wi-Fi, μ μ

802.11 , 20 z

802.11a 802.11g, 25 MHz 802.11b, WiMax μμ

μ 1.25 z 20 z. μ WiMax, Wi-

Fi, μ .

WiMax 3DES AES μ μ

μ . Wi-Fi μ

WEP WPA.

9.5 QoS

μ WiMax μ μ μ

best effort, μ base station,

μ

IP best effort μ 802.11

Wi-Fi

μ

AP

9.6 Upload

μ μ μ 802.11 μ
 backhauled ADSL, μ WiFi
 μ upload μ μ
 . [15, 16]

	WiMax 802.16	Wi-Fi 802.11
Primary Application	Broadband Wireless Access	Wireless LAN
Frequency Band	Licensed/Unlicensed 2 G to 11 GHz	2.4 GHz ISM (g) 5 GHz U-NII (a)
Channel Bandwidth	Adjustable 1.25 M to 20 MHz	20 MHz
Half/Full Duplex	Full	Half
Radio Technology	OFDM (256-channels)	OFDM (64-channels)
Bandwidth Efficiency	≤5 bps/Hz	≤2.7 bps/Hz
Modulation	BPSK, QPSK, 16-, 64-, 256-QAM	BPSK, QPSK, 16-, 64-QAM
FEC	Convolutional Code Reed-Solomon	Convolutional Code
Encryption	Mandatory- 3DES Optional- AES	Optional- RC4 (AES in 802.11i)
Access Protocol	Request/Grant	CSMA/CA
- Best Effort	Yes	Yes
- Data Priority	Yes	802.11e WME
- Consistent Delay	Yes	802.11e WSM
Mobility	Mobile WiMax (802.16e)	In development
Mesh	Yes	Vendor Proprietary

9.1: Wi ax μ Wi-Fi. [15]

10-1. μ μ

10.1.1



2008, 2.68 μμ
 μ WiMax μ μ
 , 761.659 μ WiMax
 μ μ WiMax
 Korea Telecom, μ 168.562 μ WiBro.
 2009 .

10.1.2

544.504 WiMax μ 2008,
 20% μ μ
 μ μ Iberbanda () μ 59.800
 μ , Irish Broadband () Banda Ancha (ALO) ().
 WiMax μ μ . T 2008
 μ : μ μ ,
 μ WiMax μ
 μ μ .

10.1.3

2008, ,
 126.530 μ WiMax. Pesco Telecom (),
 MTN (μ) ZAIN ()
 μ μ . Pesco Telecom 13.245 μ
 ZAIN 10.000 .
 ZAIN μ WiMax μ
 μ . TDD FDD, ZAIN
 WiMax μ TDD. Pesco Telecom WiMax
 2004 μ μ WiMax
 μ μ μ
 backhaul . DSL
 2008 μ
 μ Pesco. , μ

, μ (
 μ), WiMax μ
 . 2009 WiMax μ μ
 μ μ .
 μ μ WiMax μ μ ,
 μ WiMax μ
 μ μμ .
10.1.4 μ
 μ 395.000 μ
 WiMax 20% μ μ .
 μ μ μ μ Telecel (μ) μ
 65.000, MVS (μ) μ 50.000, Axtel (μ) μ 50.000, Orbitel (μ)
 μ 49.500 Neovia (μ) μ 23.000 μ . 64%
 μ 36% .
 μ 3.5GHz, μ
 80% .
 μ μ μ
 WiMax μ
 μ μ .
 WiMax , μ
 2.5 GHz 3.5 GHz μ
 , , μ μ 3.5 GHz
 μμ .

10.1.5 μ
 μ , Clearwire,
 μ
 , μ μ WiMax
 . Clearwire 2009 mobile WiMax
 , μ μ 8
 2009 μ 120.000.000 μ 2010.
 μ μ μ μ 78%
 22% . μ μ μ


μ WiMax μ 2008, μ 32% μ .
 μ μ μ 859.000. Clearwire
 μ , μ 469.000
 μ μ 2008.
 Inukshuk μ 200.000 μ , Kite Broadband μ 58.000,
 KeyOn μ 41.689 Barrett Xplore μ 34.273. [9]

10 -2. μ

10.2.1

μ WiMax μ
.
WiMax μ μ ,
 μ .

10.2.1

2008, 
WiMax μ μ WiMax
 μ , μ μ
 , μ
 μ .

(VoIP).

μ μ , μ μ μ , μ
 μ μ , μ μ μ
 , μ μ μ
50 km,
 , WiMax
 μ 60 Mbps (μ μ).
 μ WiMax μ μ 3,5 GHz
 μ μ
IEEE 802.16-2004,
 μ ,

WiMax Forum,
WiMax.

ADSL
WiMax (DSLAM).
6

WiMax

WiMax

WiMax

10.2.3

WiMax
2
WiMax,
[24, 35]

11 - MSITE™

11.1

To MSITE™

μμ

μ

μ

μ

μ

,

μ

.

To MSITE

μ

μ

μ

,

μ

μ

60 GHz.

20

μ

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μ

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μ

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μ

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μ

μ

μ

μ

μ

μμ

.

“wizard”,

μ

μ

,

μ

μ

,

μ

.

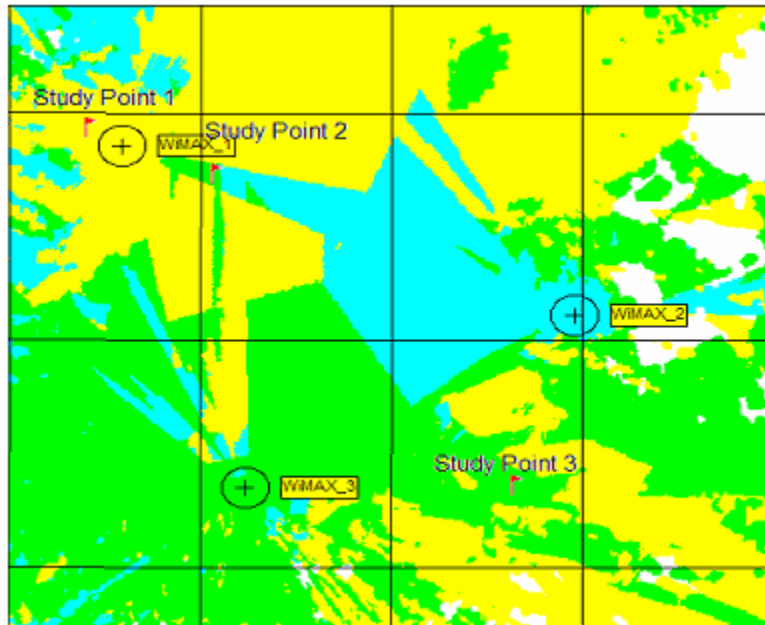


μ 11.1:

μ

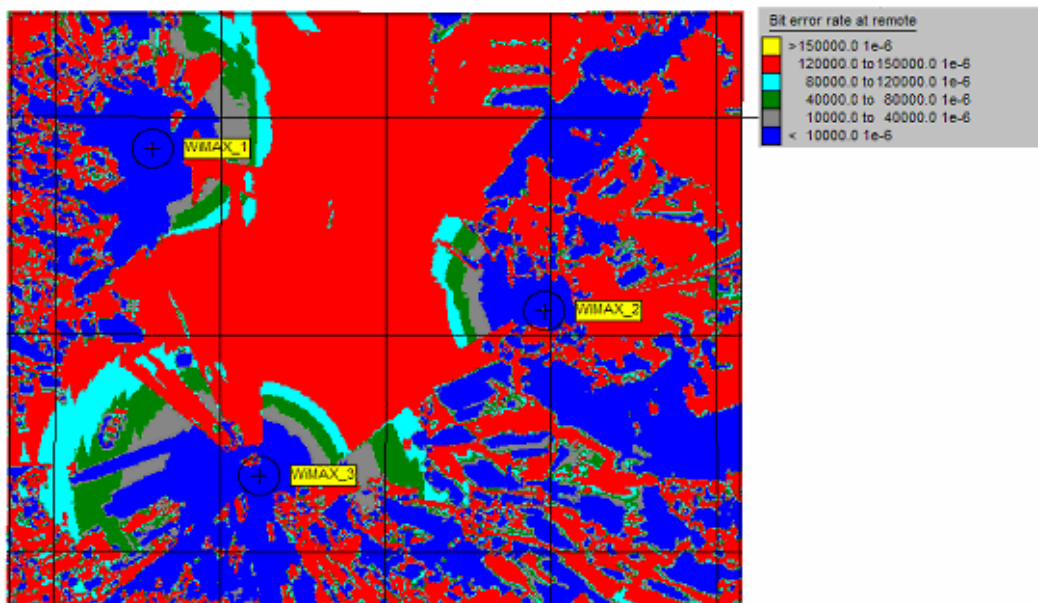
μ MSITE. [34]

server) μ μ μ (strongest) μ
 1, 2 3.
 μ μ μ

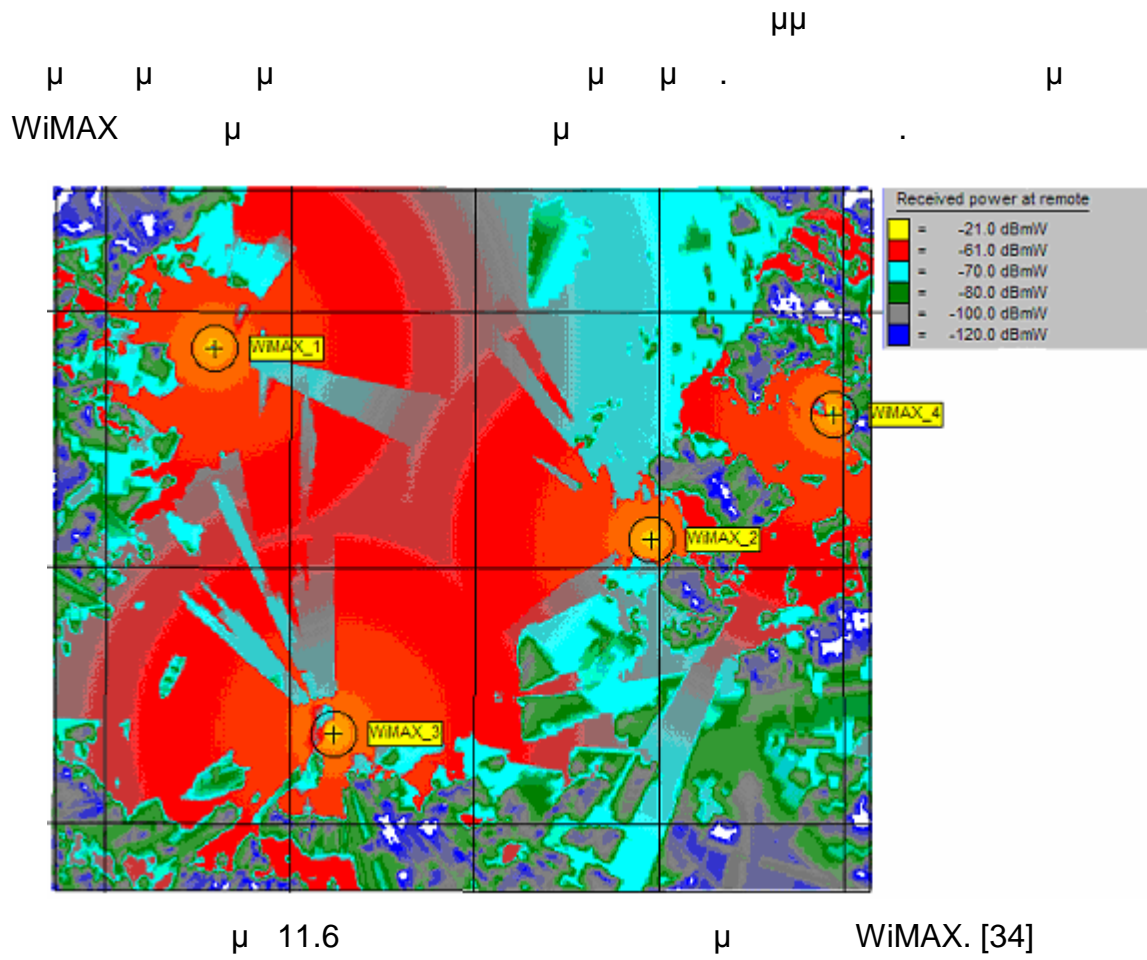


μ 11.4: μ . [34]

μ μ μ μ μ μ Msite μ
 μ μ bit μ μ μ
 μ



μ 11.5: μ μ bit [34]



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- [13] , , 2003, , 6
- [14] , (2005), μ
(WiFi) μ , μ μ μ
μ , 2.4
- [15] μ (2006), μ
-T μ μ
- [16] (2005), , μ
μ , μ μ / & μ
- [17] computer.howstuffworks.com/WiMax.htm
- [18] el.wikipedia.org/wiki/WiMax
- [19] el.wikipedia.org/wiki/WiMax
- [20] en.wikipedia.org/wiki/IEEE_802.16
- [21] grouper.ieee.org/groups/802/16/
- [22] kala-nea.blogspot.com/2009_05_01_archive.html
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- [28] www.engadget.com/2006/06/12/swedes-hit-hard-by-WiMax-waves
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- [39] www.WiMax.com/education
- [40] www.WiMax.com/education/WiMax/what_is_WiMax
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