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Keynote at SDR '10

NEC Research Activities for Wireless Innovations: Cognitive Radios and Software Defined Radios for White Space Spectrum Utilisation

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Outline

- NEC Corporation and R&D overview
- Recent trends in wireless communications
- Topics from NEC research activities on cognitive radio / software defined radio
  - System model assumptions
  - Advanced spectrum management
  - Spectrum sensing technique
  - Interference avoidance transmission
  - SDR technologies: digital and analogue baseband
- Concluding remarks

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NEC Corporation and R&D Overview

NEC Corporation and R&D Overview

- NEC Corporate Information:
  http://www.nec.com/global/about/

- NEC Research & Development:
  http://www.nec.co.jp/rd/en/

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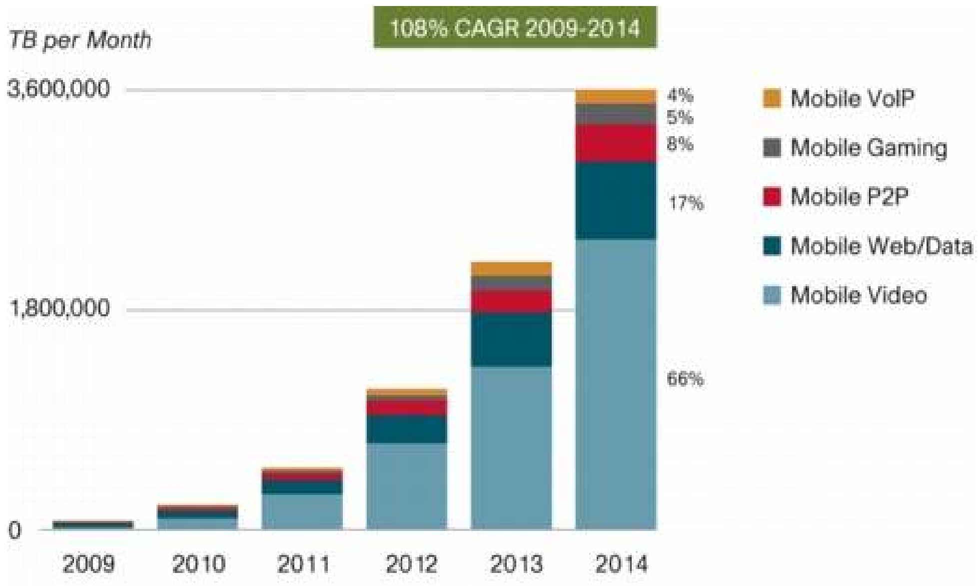
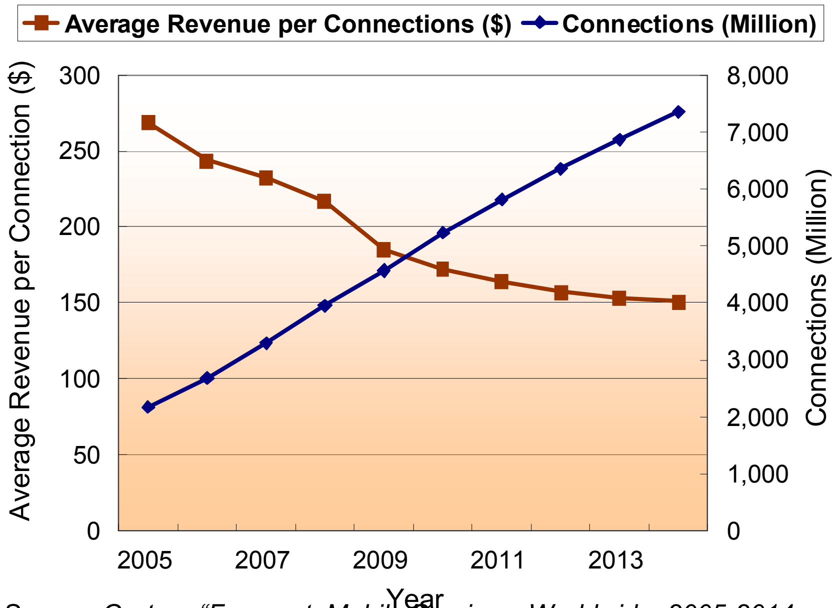
Recent Trends in Wireless Communications

Era of Ubiquitous Wireless Broadband

- Mobile internet traffic is expected to grow rapidly (108% per year), driven by the surge of mobile video and mobile web
  - Ministry of Internal affairs and Communications, Japan forecast 200 times increase of mobile data traffic in a decade since 2007
- Average revenue per connection is declining, therefore operator's revenue will stop growing as mobile penetration rate saturates in near future



Source: Cisco "Visual Networking Index: Global Mobile Data Traffic Forecast Update, 2009-2014" 9 Feb 2010.



Source: Gartner "Forecast: Mobile Services, Worldwide, 2005-2014, 4Q10 Update" 9 Dec 2010.
Chart created by NEC based on Gartner data.

A Beneficial Scenario for Both Users and Operators

- Handling of exploding data traffic (200 times) without increasing in total cost of network ownership and operation

$$\frac{\text{Increased \# of BS} \times \text{Highly Efficient Transmission} \times \text{Increased Frequency Bandwidth}}{\text{Total Cost of Network Ownership}} \xrightarrow{\textit{Target}} \frac{\times 200}{\times 1}$$

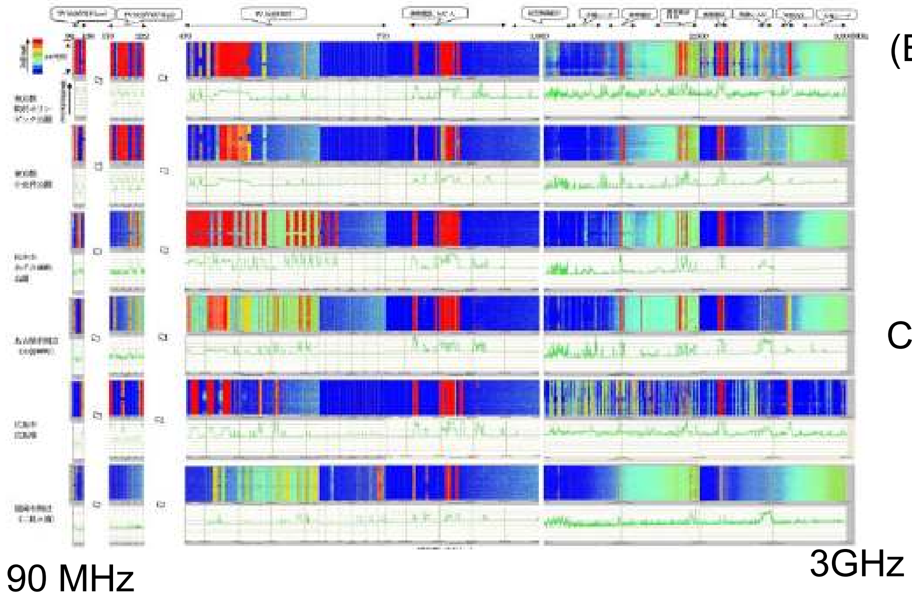
- Approaches for tackling with this increased traffic issue:
  - Installing more BSs with smaller cells
  - Traffic off loading over heterogeneous networks
  - Developing highly efficient transmission technologies
  - Making use of more bandwidth
    → **White Space spectrum utilisation**

White Space Spectrum Utilisation

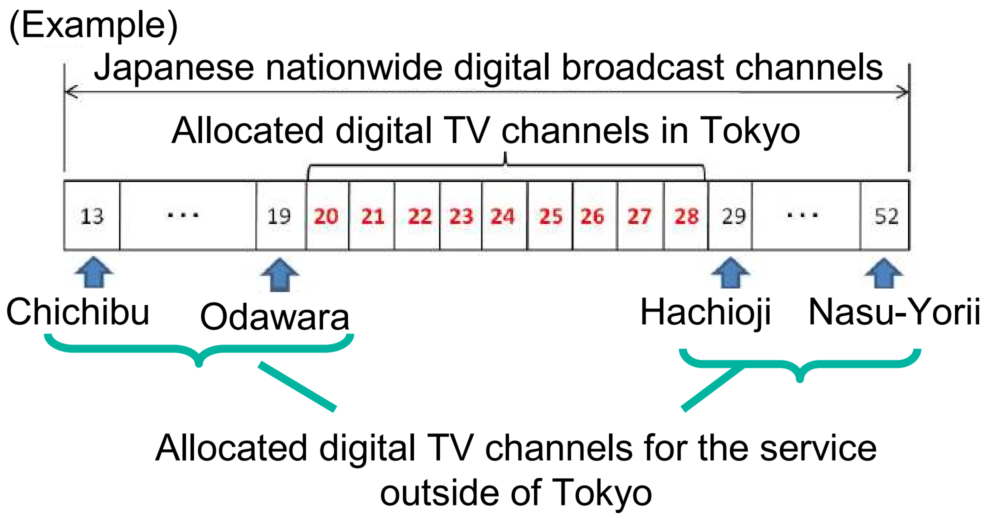
White space spectrum utilisation and cognitive radio technologies have attracted much attention globally today

- Frequencies for TV and cellular system are heavily utilised, and most of the UHF spectrum are underutilised
- Regulatory agencies, service providers, vendors and academia have been actively discussing how to utilise white spaces efficiently and effectively

Results from spectrum usage measurement campaign in Japan



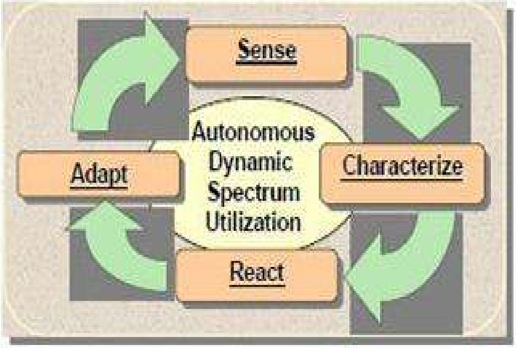
TV white space near Tokyo area



(Source: Ministry of Internal Affairs and Communications, Japan, July 2010)

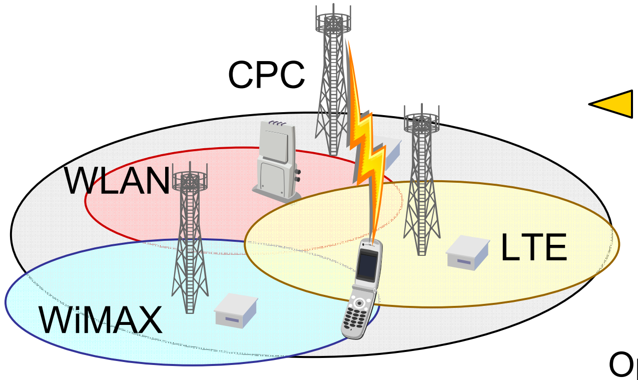
Cognitive Radio: Overview and Key Concepts

- Cognitive Radio: *a drastic solution for spectrum scarcity problem*
  - A network or a wireless node changes its transmission or reception parameters to communicate efficiently avoiding interference with licensed or unlicensed users
  - This alteration of parameters is based on active monitoring of radio environment (cognition), e.g., radio spectrum, user behaviour, network state, etc.



(Source: DARPA XG program)

- Key Concepts of CR Systems:
  - Heterogeneous wireless systems (Multi-modal CR)
  - ⇨ Opportunistic use in white space (Dynamic Spectrum Access / Spectrum sharing CR)

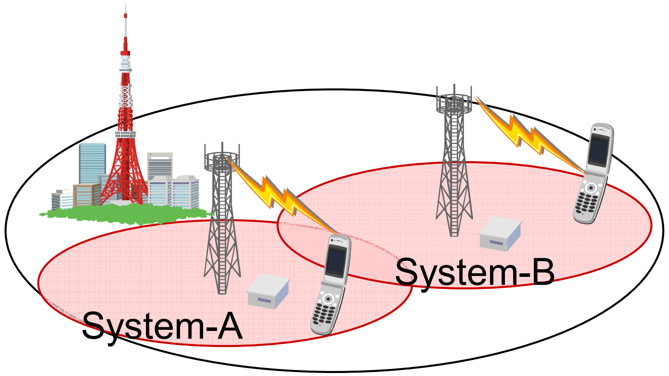


◀ Multi-modal CR

UEs support multiple RAT, and acquire radio parameters via Cognitive Pilot Channel (CPC).

Spectrum sharing CR ▶

Opportunistic radio access: White space spectrum can be shared by plural different systems.



NEC Target of Cognitive Radio Research

- Use cases for opportunistic use of WS spectrum:
  - Fixed or nomadic wireless communication systems
  - Short range wireless communications
  - Not many studies on mobile communication systems for wider range
- NEC target use case: cellular type of Cognitive Radio systems, referred to as **Cellular Extension system model**

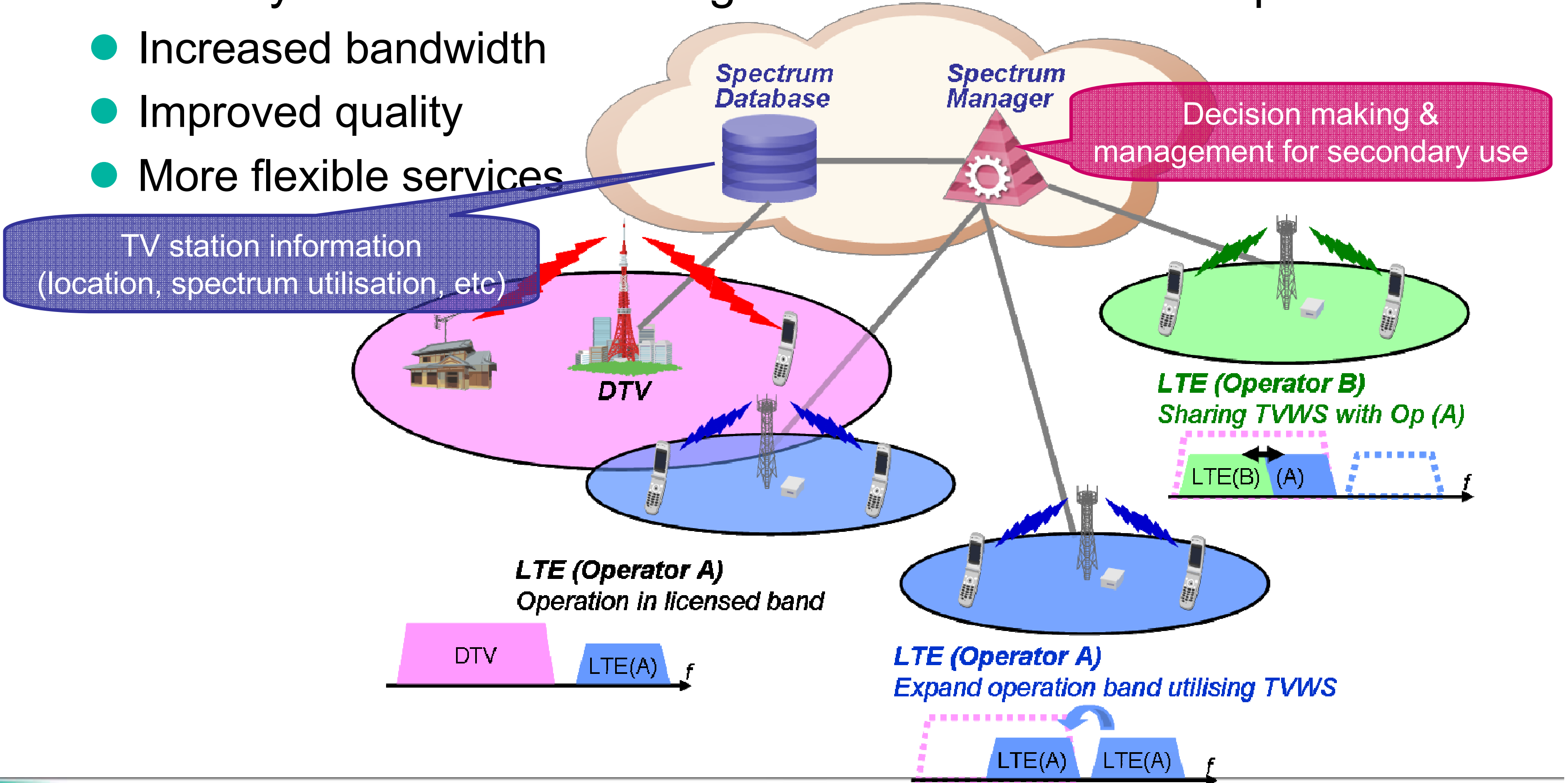
Cognitive Radio mobile networks with QoS functionality utilising White Space spectrum

- Why Cellular Extension?
  - The most reliable and proven system: easier to manage interference problems
  - High technical challenges for realising the system with mobility for mid -wider range
    → Developed technologies may be applicable for other CR use cases

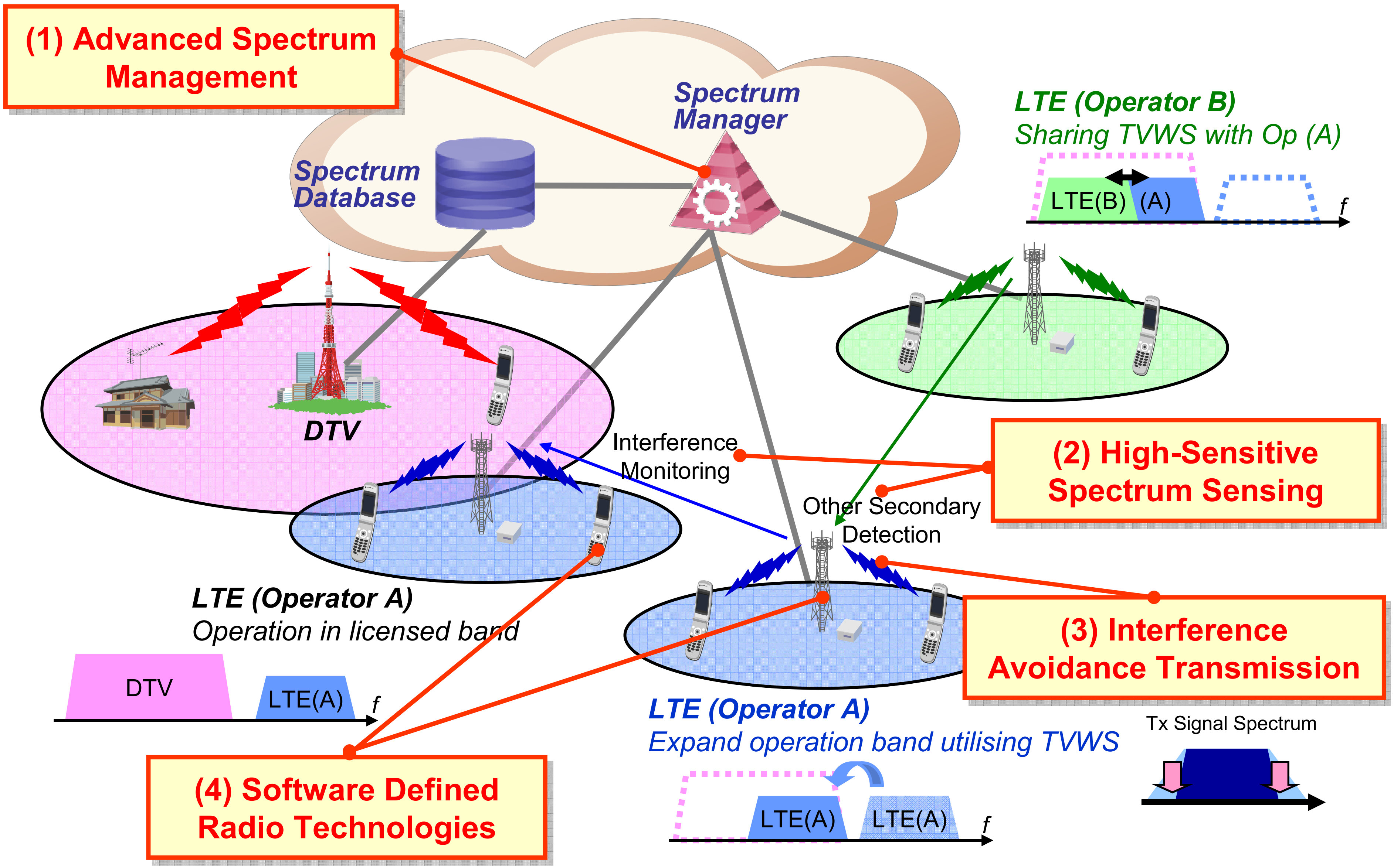
Topics from NEC Radio Research Activities on Cognitive Radio / Software Defined

The Cellular Extension System Model

- Cellular type of CR systems operating in White Spaces
- Cellular operators extend their operational band in TVWS for secondary use without causing harmful interference to primaries
  - Increased bandwidth
  - Improved quality
  - More flexible services



Technical Challenges for Realising the Cellular Extension



(1) Advanced Spectrum Management

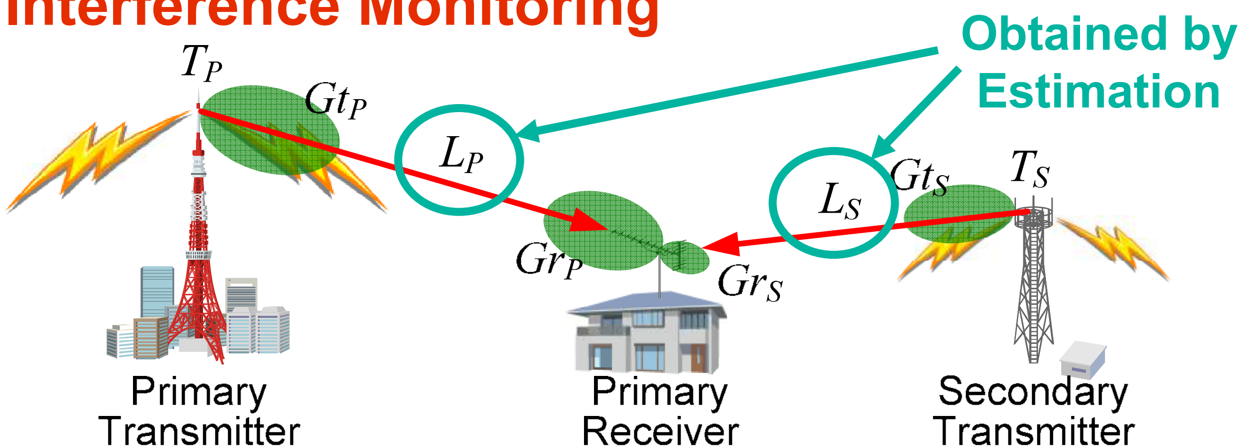
Basic Principle:

- Control secondary Tx power to keep interference below allowed level at the primary receiver
- Allowable secondary Tx power: $P_{s,max}$

$$P_{s,\max} = \left(P_p + Gt_p - L_p + Gr_p\right) - \left(Gt_s - L_s + Gr_s\right) - CIR_{req} - M$$

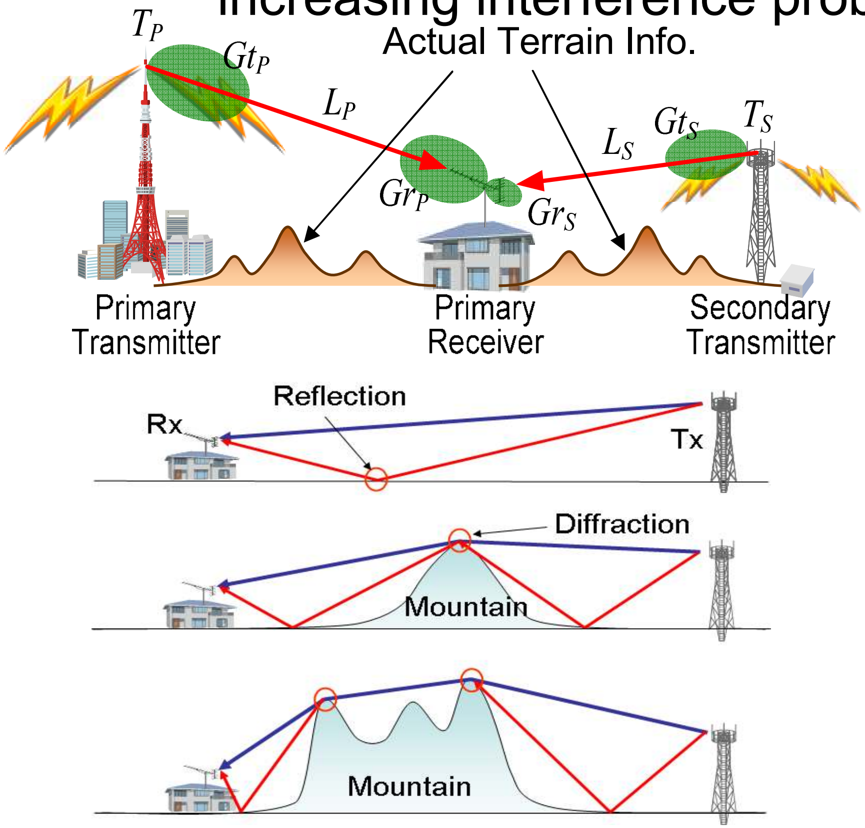
- For enhancing white space utilisation opportunity, a key is to minimise margin M (for compensation of path-loss estimation error)

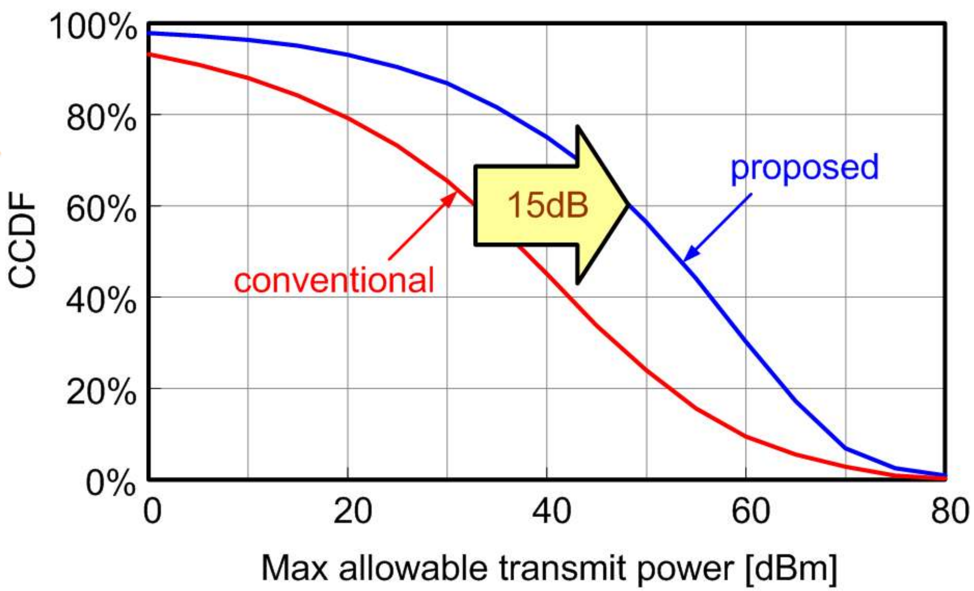
Two approaches for improving the estimation accuracy:
- Site-specific Interference Estimation;
- Interference Monitoring



(1) ASM with Site-Specific Interference Estimation

- Applying site-specific propagation model for CIR estimation
  - Estimate CIR (primary and secondary signal level) taking into account actual terrain information stored in a database
  - The proposed site-specific interference estimation can achieve about 15 dB higher transmission power for secondary without increasing interference probability

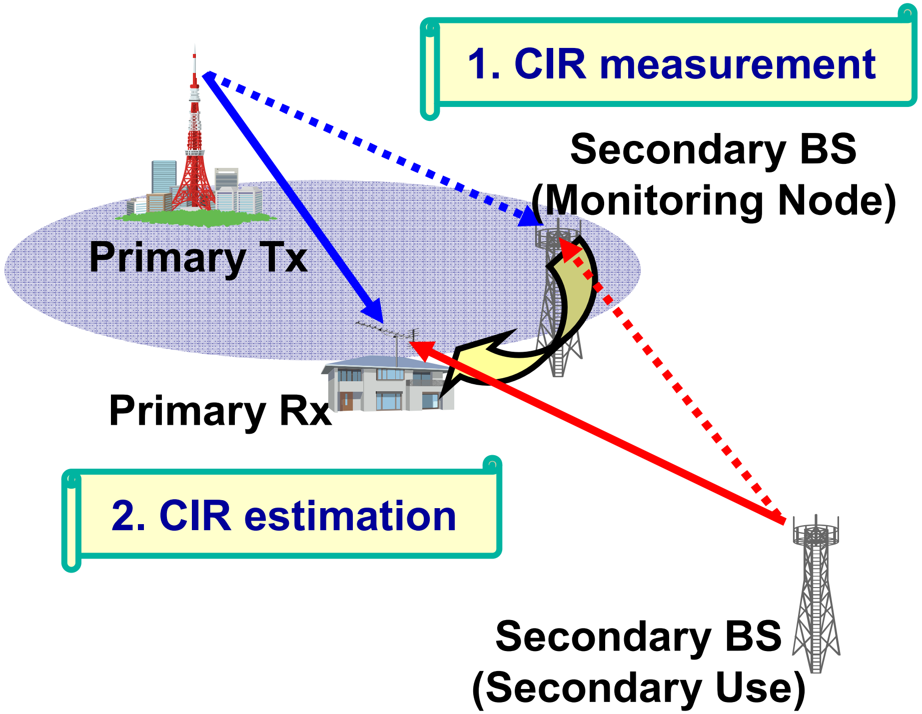




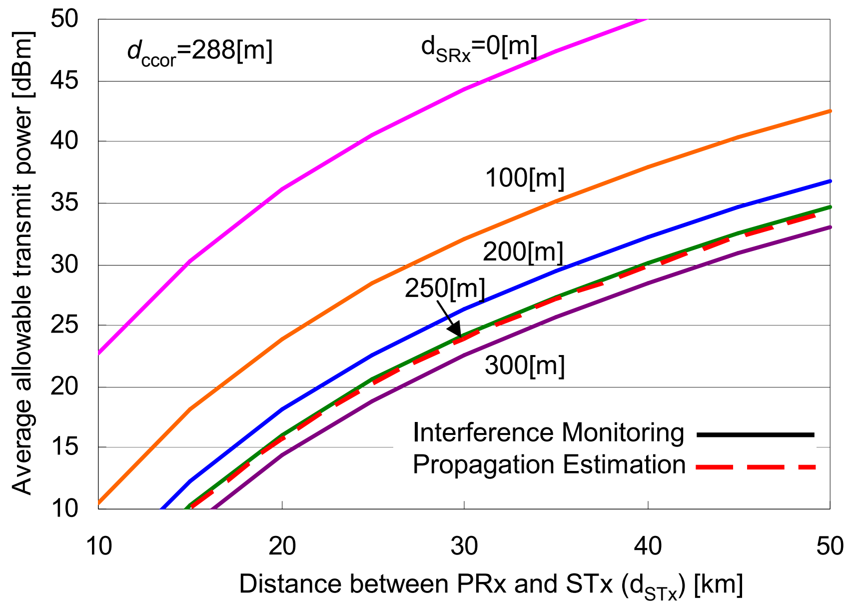
T Nakamura, H Sugahara, K Muraoka, M Ariyoshi, "Site Specific Interference Estimation for Advanced Spectrum Management in Cognitive Radio System over White Space Spectrum," *IEICE Technical Report, SR2010-65, Oct 2010*

(1) ASM with Interference Monitoring

- Spectrum sensing for measuring interference signal level, as well as the primary signal level
  - Actually measure CIR (primary and secondary signal level) at the monitoring node located near the primary receiver
  - Estimate CIR at the primary receiver by using the measurement results



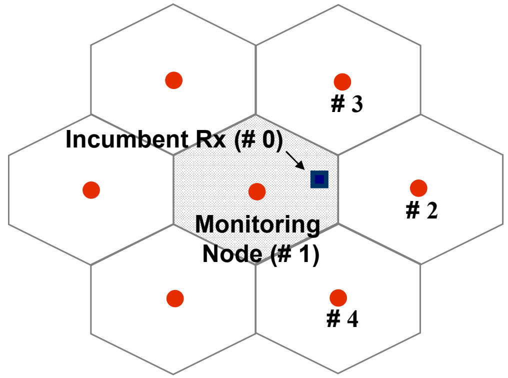
IM can increase the secondary Tx opportunities for d_{SRx} < 250m

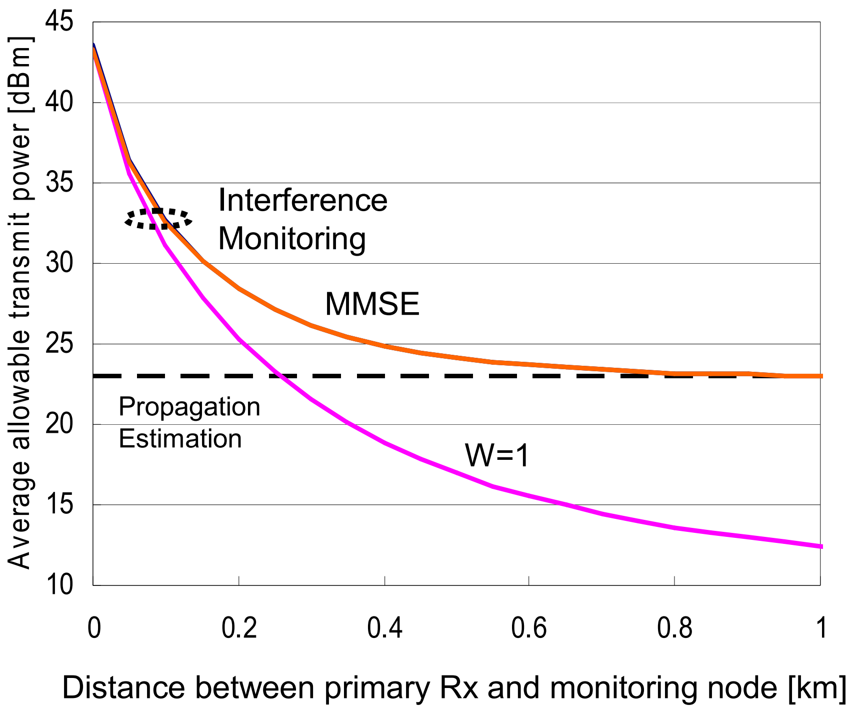


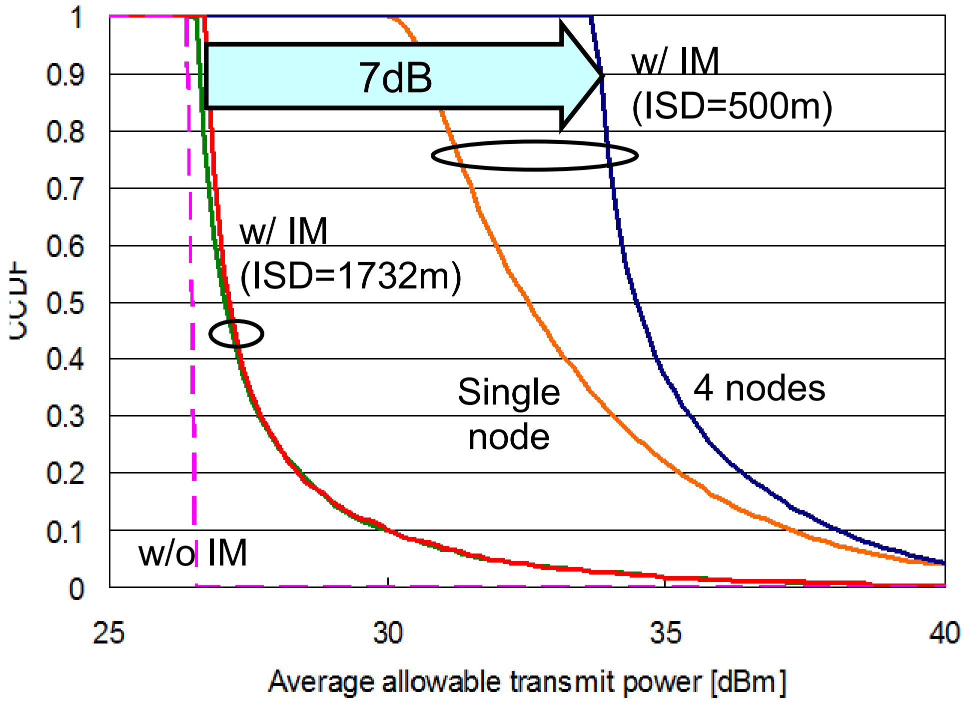
K Muraoka, H Sugahara, M Ariyoshi, "A Cognitive Radio Mobile Network Utilising White Space Spectrum (3) - Interference Monitoring for Advanced Spectrum Management," *Proc of IEICE Society Conference 2010, B-17-2, Sept 2010*

(1) ASM with Enhanced Interference Monitoring

- MMSE based compensation for enhancing reliability of path loss estimation error
- Cooperative Interference Monitoring by multiple monitoring nodes







K Muraoka, H Sugahara, M Ariyoshi, "Monitoring Based Spectrum Management for Expanding Opportunities of White Space Utilisation," *submitted to IEICE DySPAN 2011*

(2) Spectrum Sensing for DSA

Requirements on Spectrum Sensing:

- High reliability in detection performance P_D to ensure non-interfering coexistence
- Robustness against noise uncertainty: stable false alarm rate P_{FA}
  - Estimation error in noise power level due to interference and channel conditions (fading and shadowing)
  - Difficulties in setting appropriate detection threshold under such conditions with noise uncertainty

Maximum Cyclic Autocorrelation Selection (MCAS):

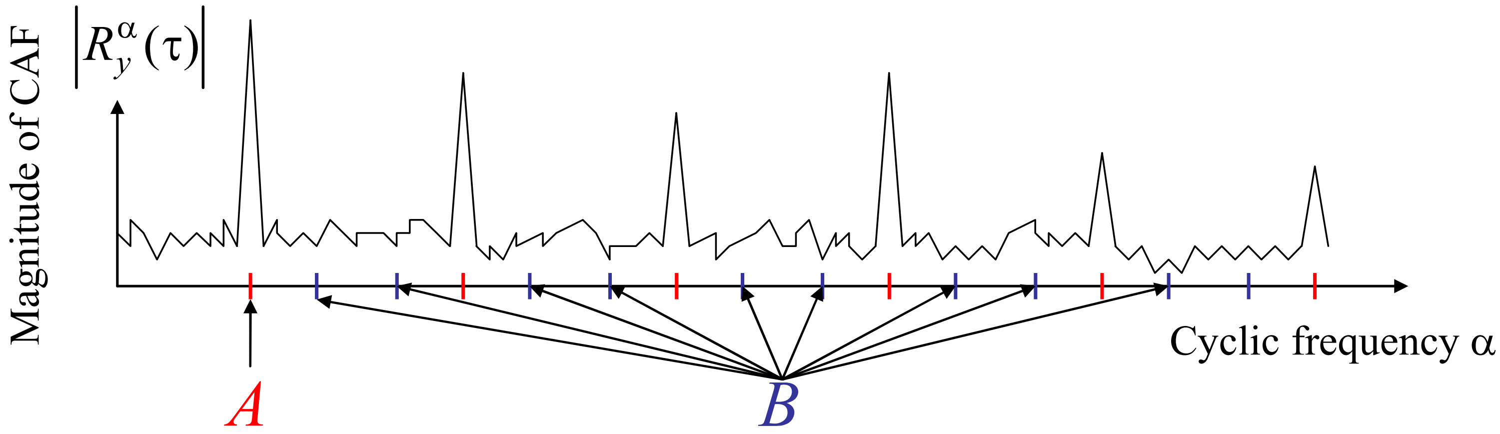
- A Cyclostationary Feature Detection based spectrum sensing aiming for high performance in P_D
- No noise power information required aiming for robustness against noise uncertainty

(2) MCAS Spectrum Sensing

Maximum Cyclic Autocorrelation Selection

Exploit peak position of Cyclic Autocorrelation Function $R_x^{\alpha}(\tau)$

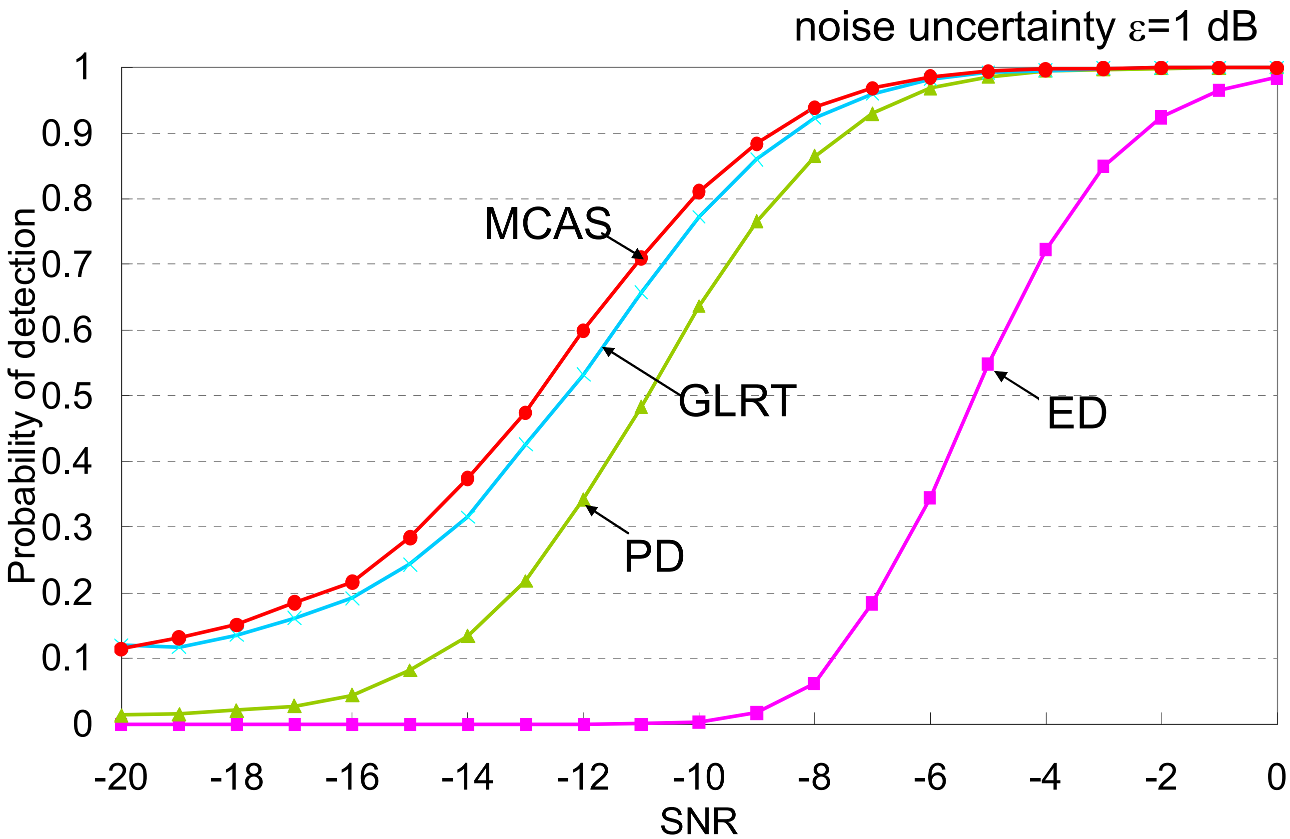
1. Calculate several CAF values at peak A and non-peaks B
2. Select a position which gives the largest CAF
3. If the selected position is A, decide primary system is present



MCAS achieves robustness against noise uncertainty, because it doesn't need noise power information

K Muraoka, M Ariyoshi, T Fujii, "A Robust Spectrum-Sensing Method Based on Maximum Cyclic Autocorrelation Selection for Dynamic Spectrum Access," *IEICE Trans Commun, vol. E92-B, no. 12, Dec 2009*

(2) Performance of MCAS Spectrum Sensing



- MCAS achieves good detection performance as well as robustness against noise uncertainty
- Another noteworthy feature of MCAS is extremely reduced computational complexity
  - 15% of multiplication and 9% of addition comparing to conventional GLRT

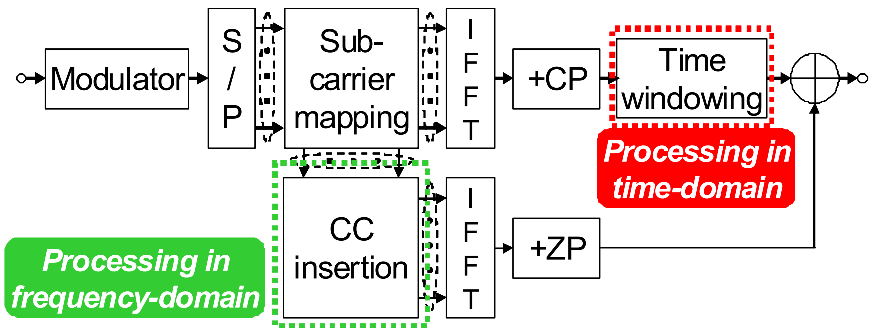
(3) Interference Avoidance Transmission

Objective:

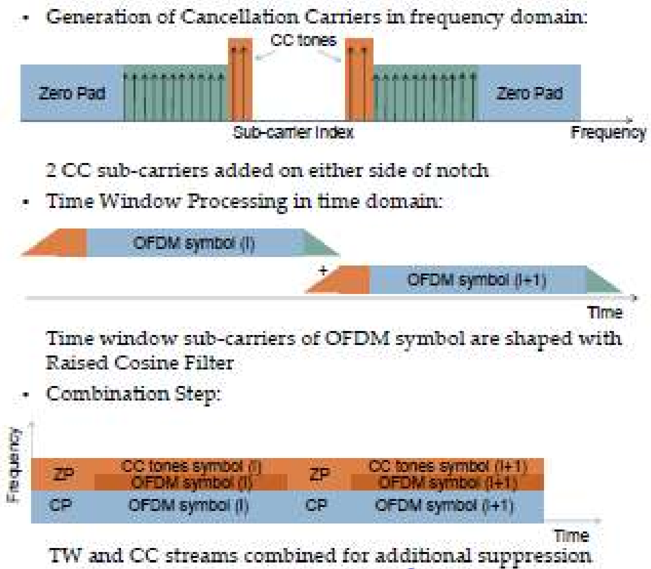
- Suppress out-of-band emission to minimise interference caused by secondary system

Interference Avoidance transmission by Partitioned Frequency- and Time-domain processing (IA-PFT):

- Combination of Cancellation Carriers in frequency-domain and Time Windowing in time-domain
- Transmitted Q sub-carries near the interference avoidance band are processed for CC calculation
- The rest of the sub-carries are suppressed by TW



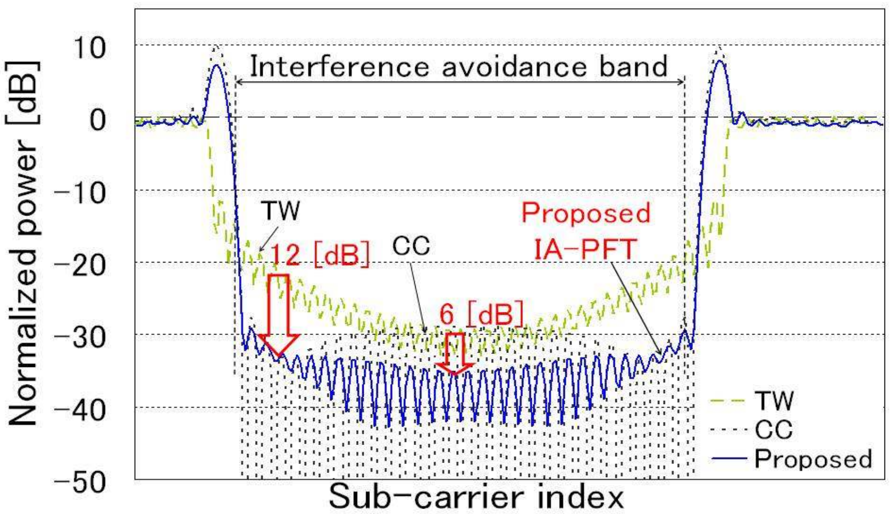
Transmitter structure (IA-PFT)

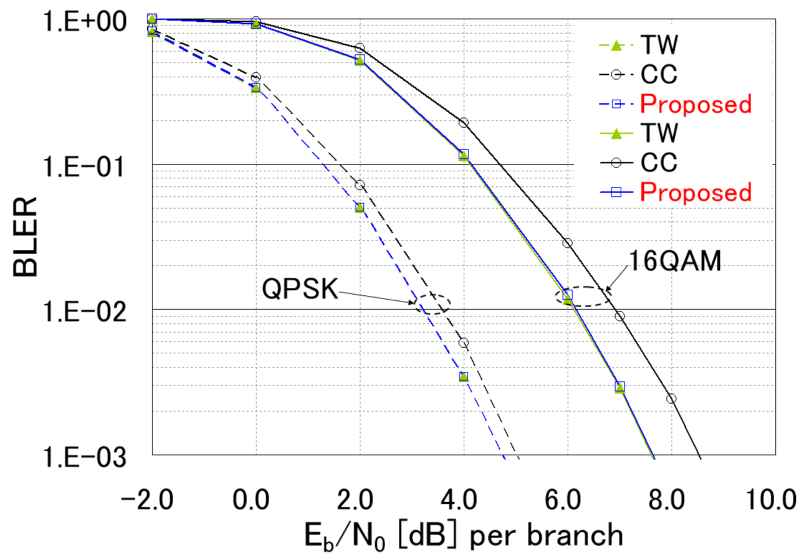


Partitioned processing of tx sub-carriers

(3) Performance of IA-PFT Transmission

- The proposed IA-PFT outperforms the conventional methods in terms of interference suppression gain.
  - The interference power spectrum density can be reduced by 6 [dB] at the centre of the notch and by 12 [dB] at the edge
- The IA-PFT realises transmission performance as good as that attained by a conventional interference avoidance method.
- We implemented the IA-PFT with spectrum sensing functions on USRP2 and confirmed operation in real world.



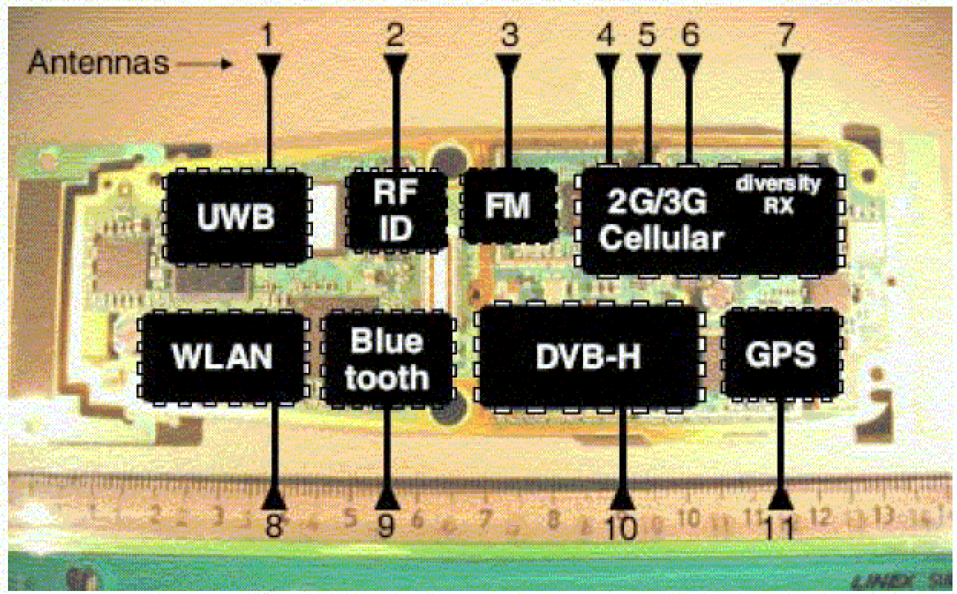


Y Futatsugi, M Ariyoshi, “Interference Avoidance Transmission by Partitioned Frequency- and Time-domain Processing,” *submitted to IEEE DySPAN 2011*

(4) Software Defined Radio

Various wireless standards can be supported with a single chip that can change the wireless function based on the downloaded software. This realises the lowest cost and smallest form factor terminal.

Conventional Technologies



Yrjö Neuvo, CTO, Nokia at ISSCC2004

Needs individual chip for each wireless standard

Software Defined Radio

No need multi-chip.
Smallest form factor

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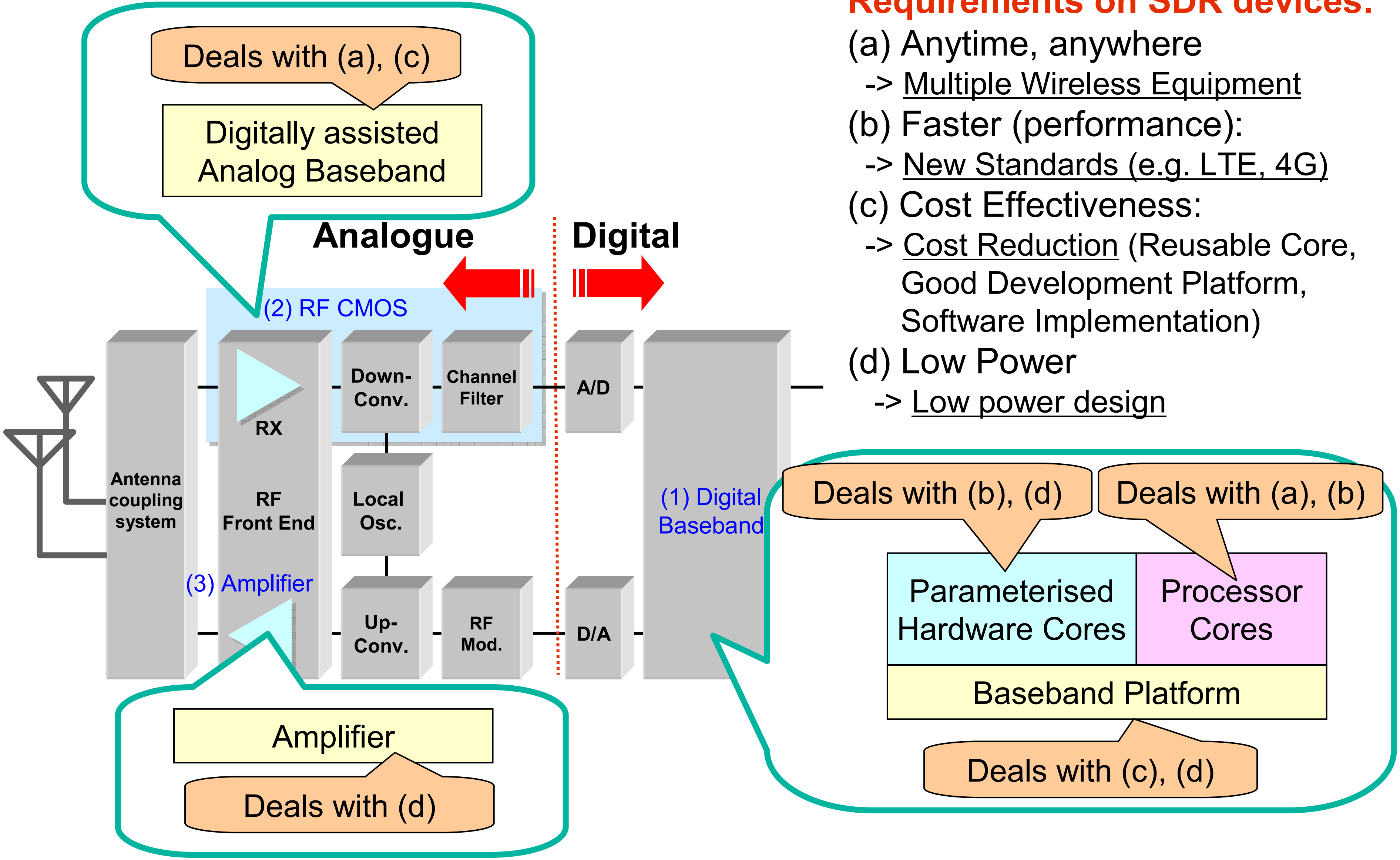
(4) NEC View on Flexible Wireless Device Platform



Requirements on SDR devices:

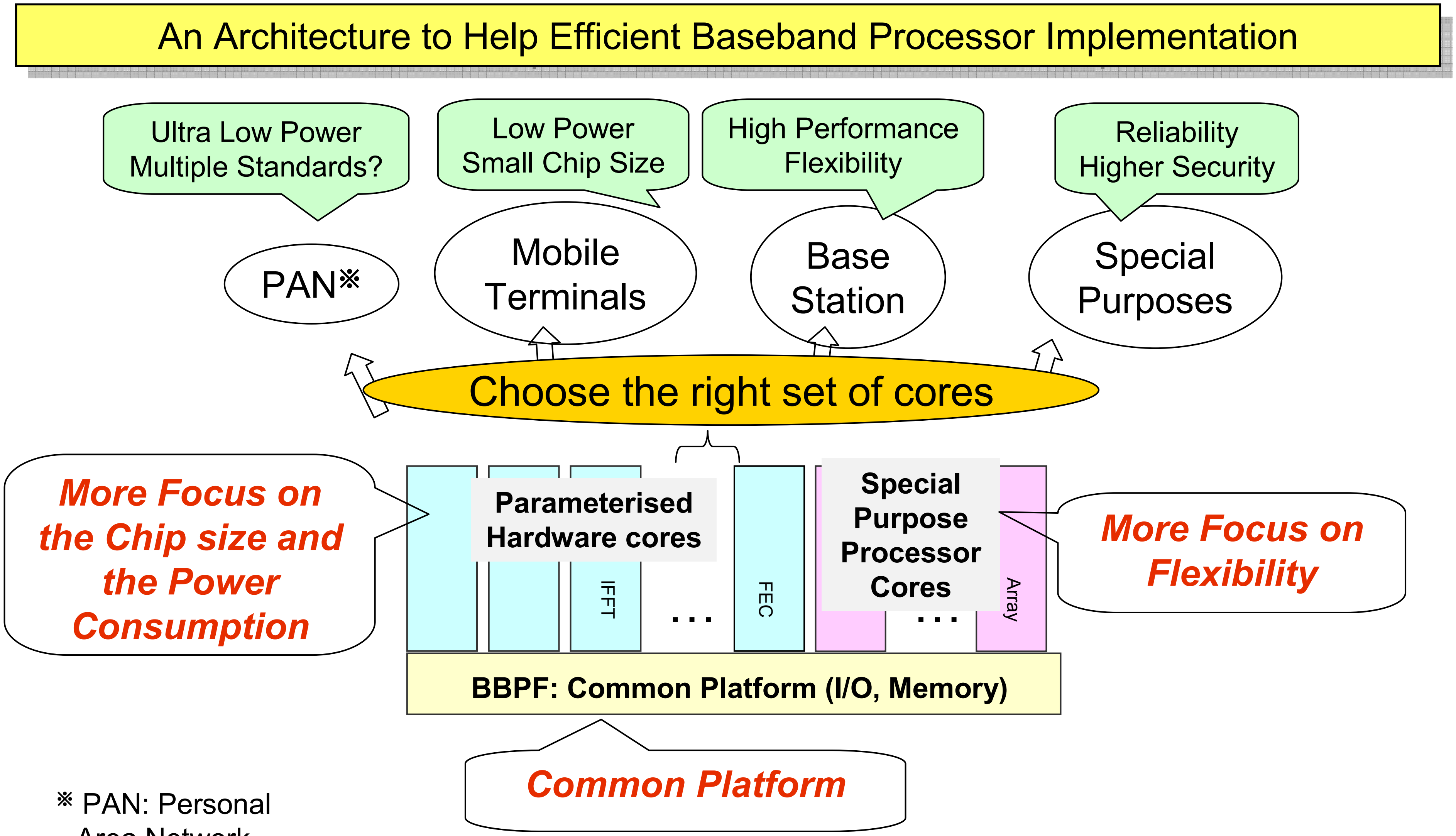
(a) Anytime, anywhere
-> Multiple Wireless Equipment

(b) Faster (performance):
-> New Standards (e.g. LTE, 4G)

(c) Cost Effectiveness:
-> Cost Reduction (Reusable Core, Good Development Platform, Software Implementation)

(d) Low Power
-> Low power design

(4-1) Digital Baseband Processor Framework



※ PAN: Personal Area Network

(4-1) Baseband Platform (BBPF)

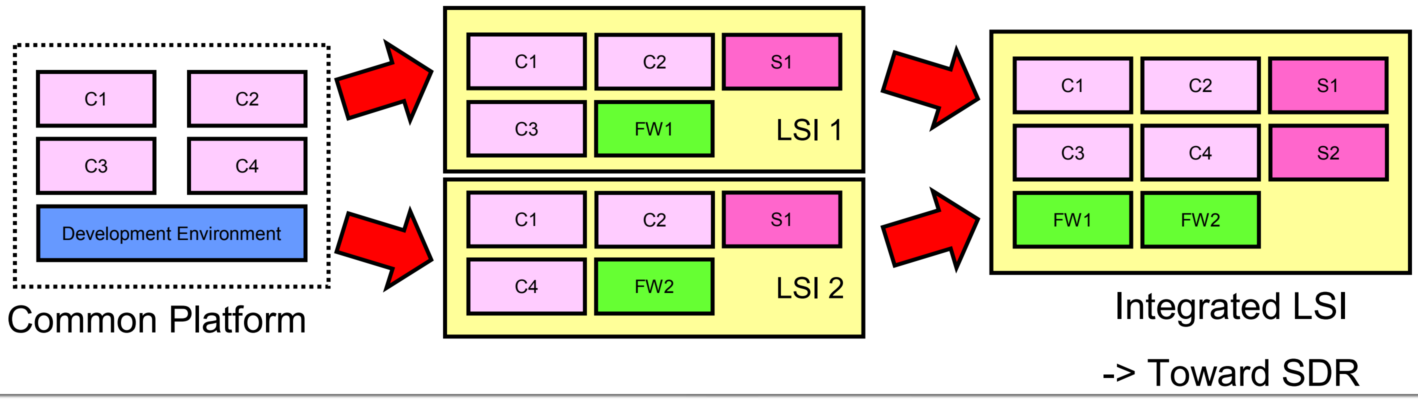
Target: A Platform for efficiently implementing baseband LSI's with versatile requirements

Basic Ideas behind

- Standardisation of core interfaces, execution control, and development environment
- Cores designed to meet the above standard can be (re)used for efficiently implementing a variety of baseband processors

Short term goal: Reduction of development period and cost

Mid term goal: Easy implementation of SDR processor by re-using common cores

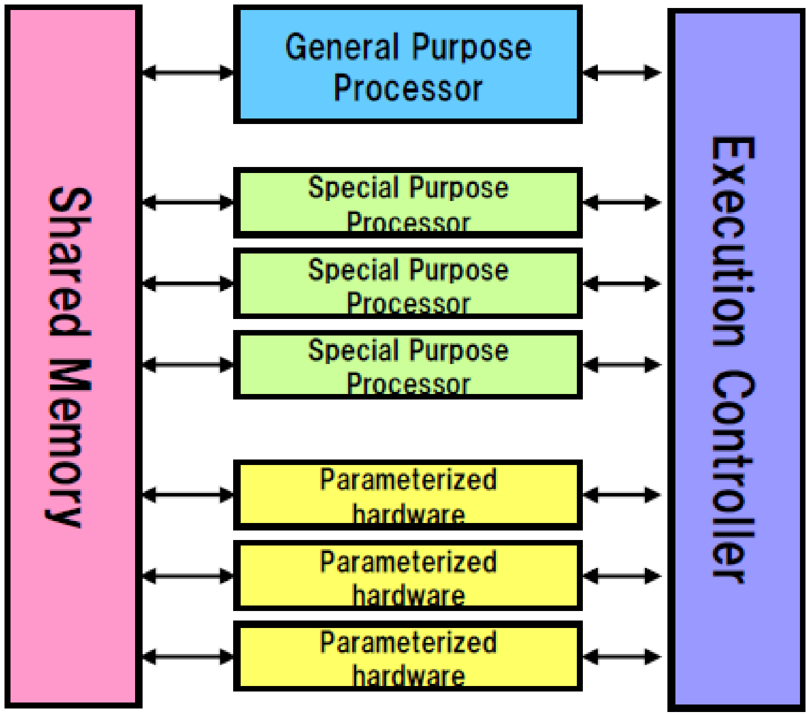


(4-1) BBPF Architecture in Brief

Heterogeneous multi core processor configuration with parameterised hardware cores and special purpose processor cores

1. Each functional block is mapped to one of the following three core types
   - Parameterised Hardware core
   - Special Purpose Processor core
   - General Purpose Processor core
2. Shared Memory to transfer data among cores
3. Execution Controller to manage execution of cores

- Each core performs its function independently and efficiently
- Common interface (e.g. protocol, data type) among cores



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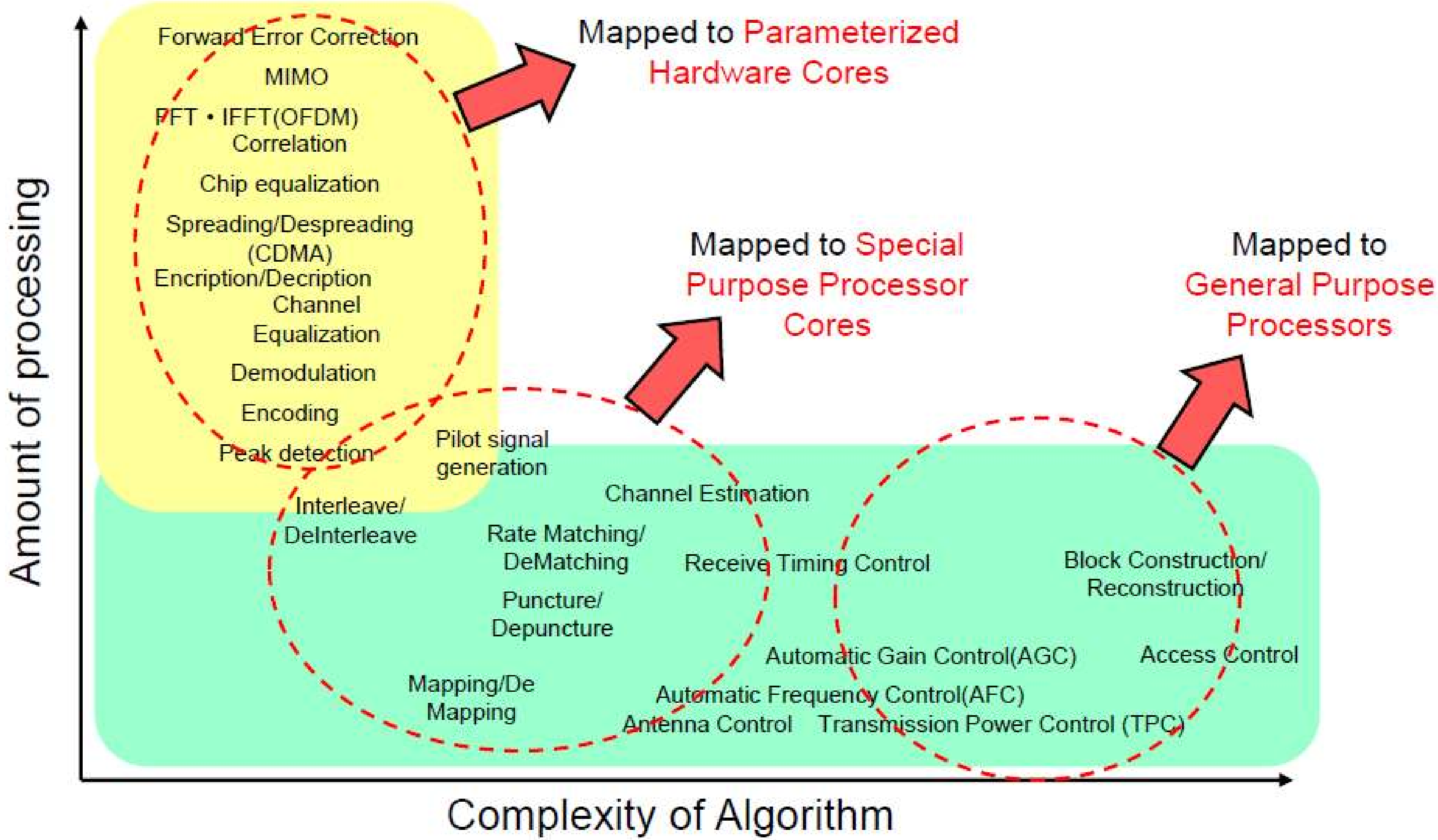
(4-1) How Do We Map Functions to Cores?

- Functional blocks are classified according to the complexity of algorithm and the amount of processing



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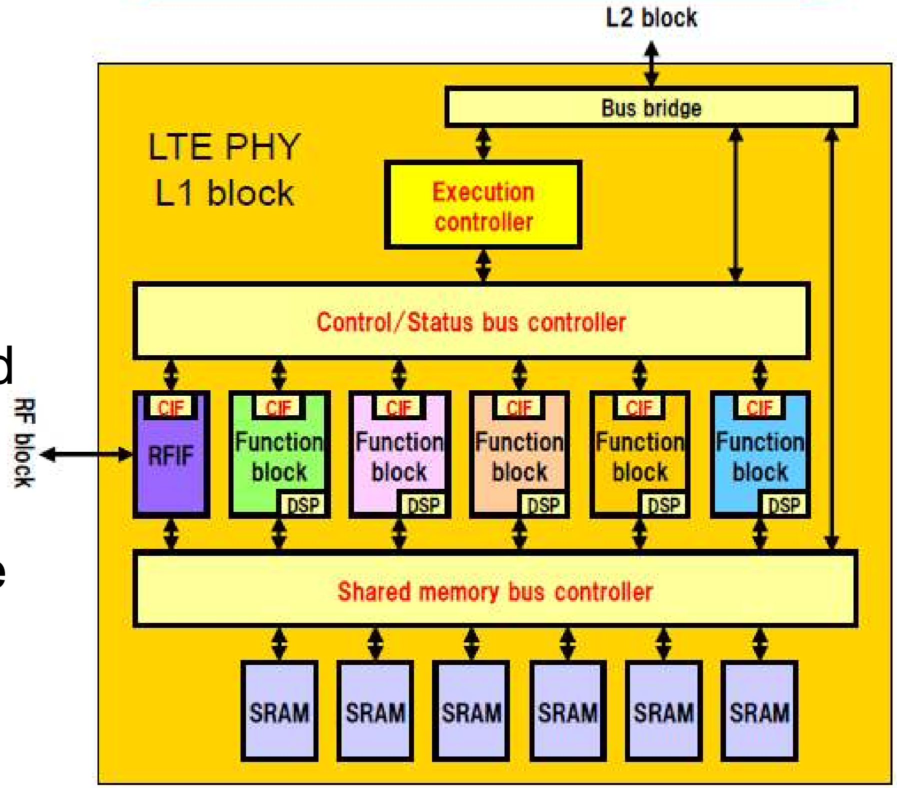
(4-1) BBPF Will Be Applied to NEC LTE Phones

- Most of the baseband LSIs for NEC mobile phones employ a many-DSP architecture which is an origin of the BBPF
- BBPF will be applied to the baseband processors in the near future NEC LTE mobile phones (and other companies')
  - Flexible architecture can deal with the progress of LTE standards and multi-RAT functionality
  - Low power consumption is achieved with heterogeneous core configuration and parameterised hardware blocks



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(4-1) NEC Digital BBPF Shipped to the Real World

- A baseband chip design for LTE terminals has been completed (Joint work with NTT DoCoMo, Panasonic, Fujitsu)

20091002N0630)

エンジニアリングサンプル開発完了

LTE端末チップセット

ドコモなど4社

NTTドコモ、NEC、パナソニックモバイル、富士通の4社は1日、LTEに対応して共同開発中の通信プラットフォーム「LTE−PF」対応LTE端末チップセットのエンジニアリングサンプル開発を完了、主要機能について性能評価中であると発表した。「LTE−PF」はLTE規格に準拠して、受信時最大100メガbps、送信時最大50メガbpsの高速データ通信を可能にする。W−CDMAおよびGSMの通信システムとの連携も可能で、LTEエリアとW−CDMA/GSMエリア間の移動時にも利用者が意識することなくスムーズな切り替えを可能とし、シームレスな通信環境を実現する。

4社は今後、「LTE−PF」を日本国内および全世界の携帯電話市場に向けてライセンス提供することを検討中。

これらの開発成果はスイス・ジュネーブで開催される「ITUテレコムワールド2009」（会期10月5−9日）、幕張メッセで開催される「シーテックジャパン2009」（会期10月6−10日）でも一部展示される。

8面 (20091002N0452)

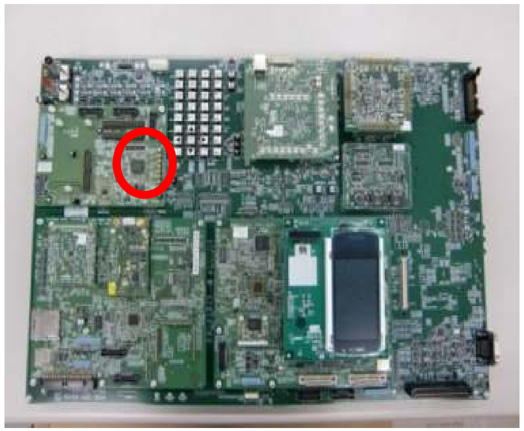
LTE対応チップセット

ドコモなど共同開発

NTTドコモ、NEC、パナソニックモバイルコミュニケーションズ、富士通の4社は1日、2010年にサービスが始まる第3・9世代携帯電話「LTE」の通信プラットフォーム（基盤）機能を盛り込んだ端末用LSI（チップセット）を共同開発したと発表した。ハードウエアに実装し、主要機能の性能評価を進める。

4社は06年12月にLTEの通信基盤「LTE−PF」の共同開発に着手した。LTE−PFは欧州・米国・アジアの標準化団体で組織する「3GPP」によるLTE規格に準拠している。4社はチップセットの製品化を進め、国内外の携帯端末メーカーや半導体メーカーに売り込む。

LTEは光回線並みの速度でデータ通信できるのが特徴。国内では10年末からドコモがサービスを始める見通し。



- Base stations with CORSA Engine are now being shipped to NTT DoCoMo.

LTE用無線基地局装置を出荷

NECがドコモに

NECはこのほど、今年12月にLTEサービスを開始するNTTドコモに商用無線基地局装置の出荷を開始した。

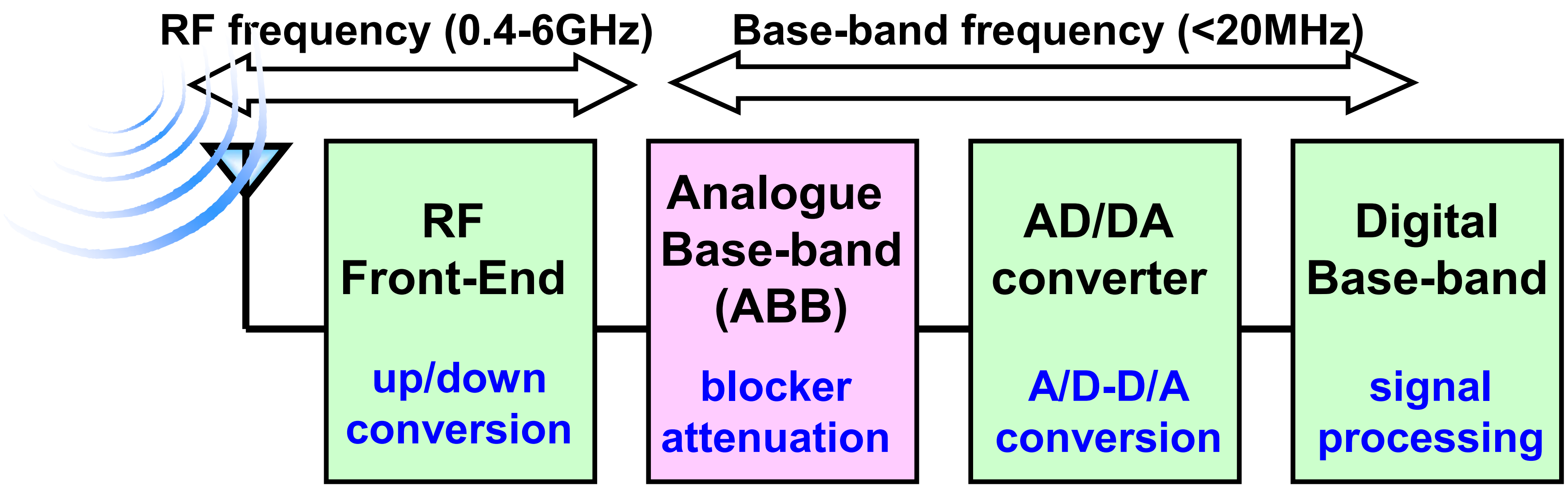
同装置は最先端のデバイス技術により、幅508×高さ199×奥行き391ミリと、従来の同社3G基地局比約4分の1の小型化を実現した。

ソフトウエアの書き換えのみで国際標準規格「3GPP」改定などに柔軟な対応が可能な高性能プログラマブルプロセッサを採用、将来のサービス拡大や機能拡張にも対応している。

NECは無線基地局のほか、LTEのコアネットワーク装置、無線基地局とコアネットワーク装置を結ぶスイッチをNTTドコモに納入。また、LTE携帯電話端末の開発・製造ベンダーでもあり、通信インフラから端末までトータルシステムプロバイダとして、NTTドコモの商用LTEサービス実現をサポートする。

(4-2) Analogue Baseband

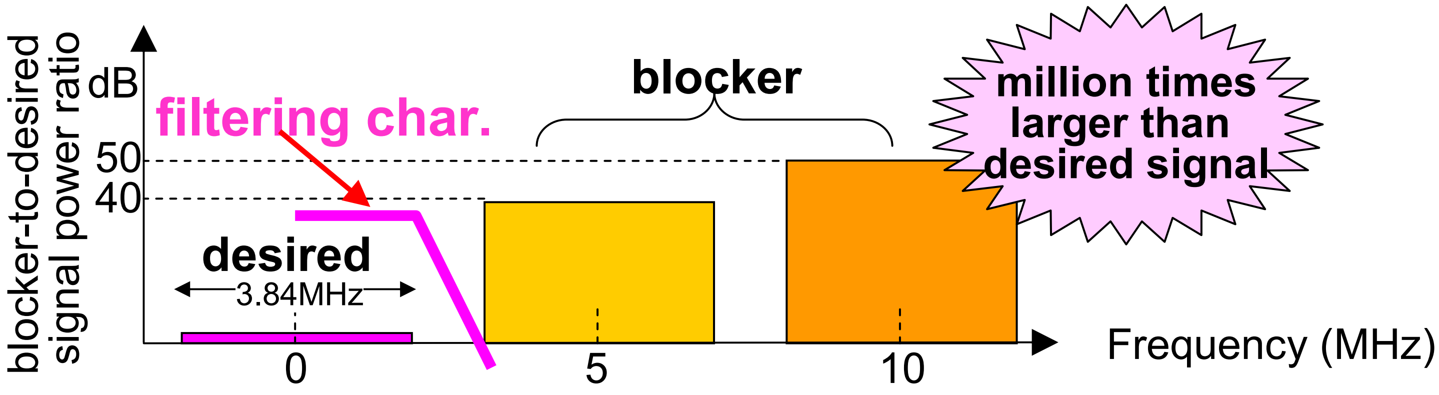
- For SDR to come true, each component of the wireless system must have re-configurability
  - up- and down-convert the base-band signal to and from the radio-frequency (RF) band
  - attenuate the blocker signal and/or channel selection
  - Analogue-to-Digital conversion
  - Signal processing for each wireless standard
- Re-configurability in the Analogue Base-band block is the key issue, because it has to attenuate different types of blocker signals for different wireless standards .



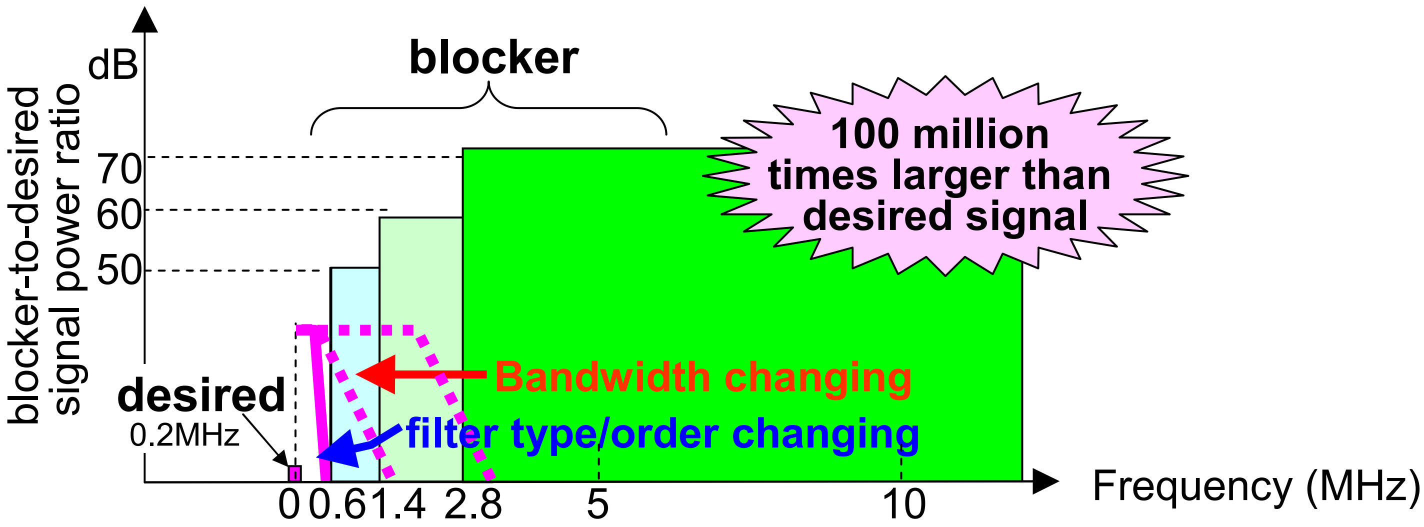
(4-2) What Is Difficult for Attenuation?

- Each wireless standard has a different channel bandwidth, blocker.
- The blocker signal is strong and very close to the desired signal.

WCDMA

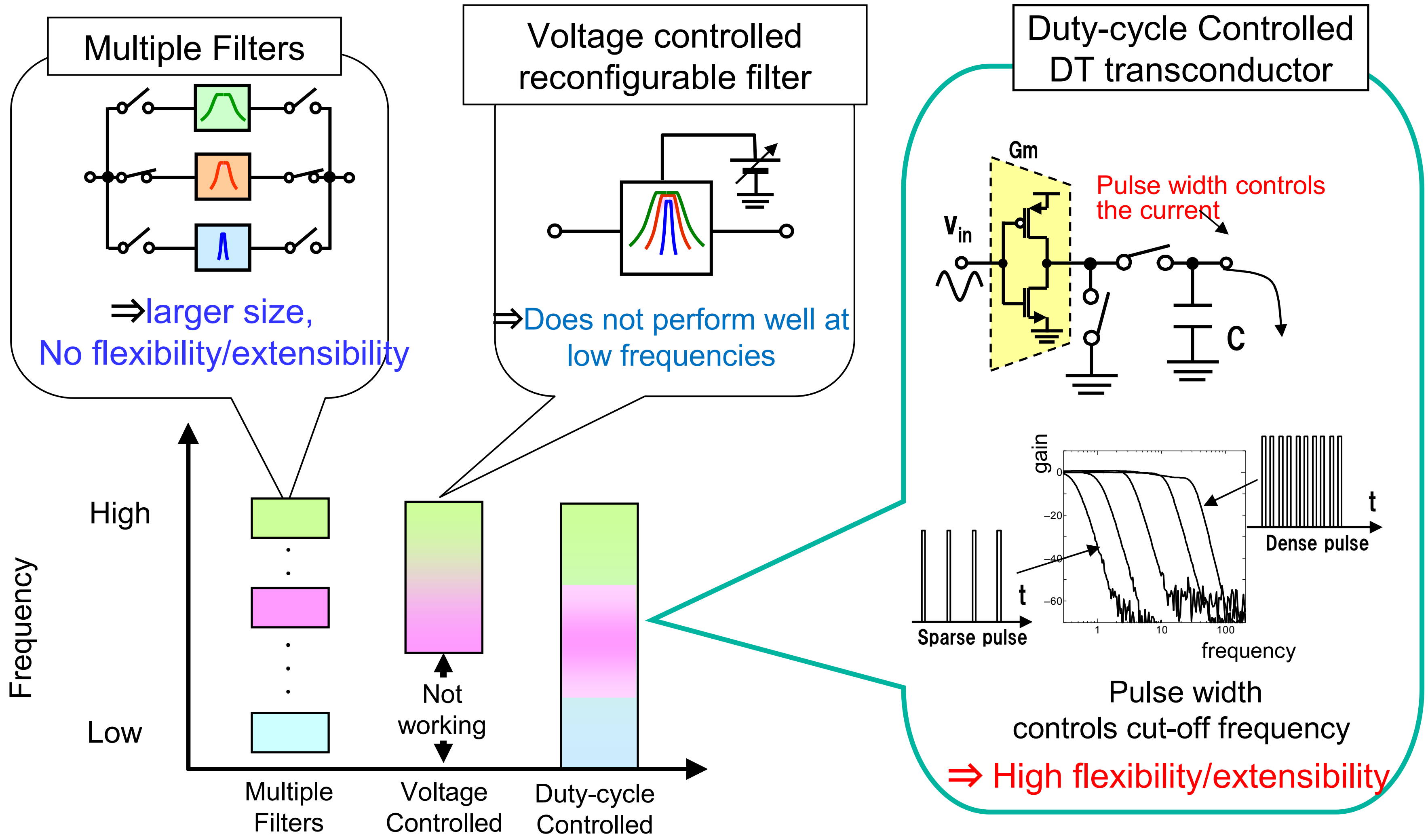


GSM

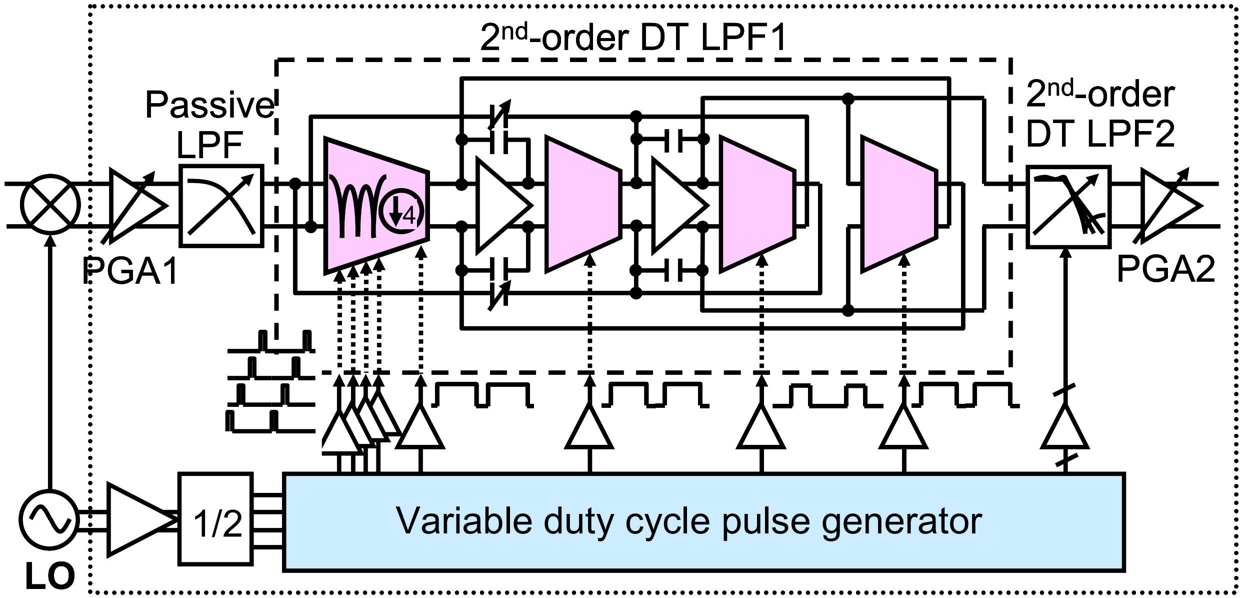


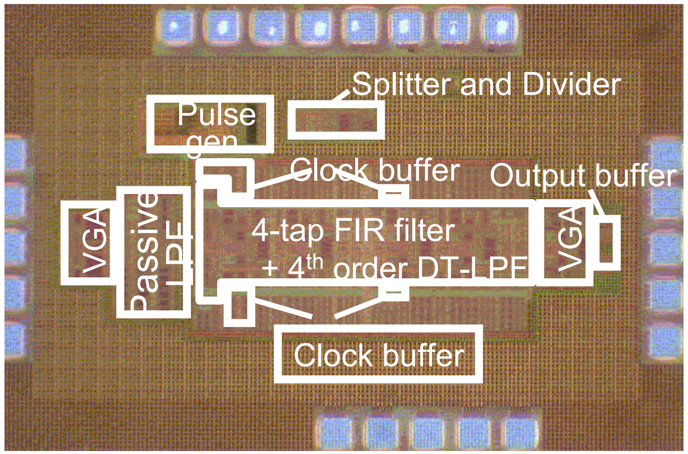
(4-2) How Do We Achieve Re-configurability in ABB?

Duty-cycle controlled DT transconductor



(4-2) Reconfigurable ABB: Block Diagram and Die Photo



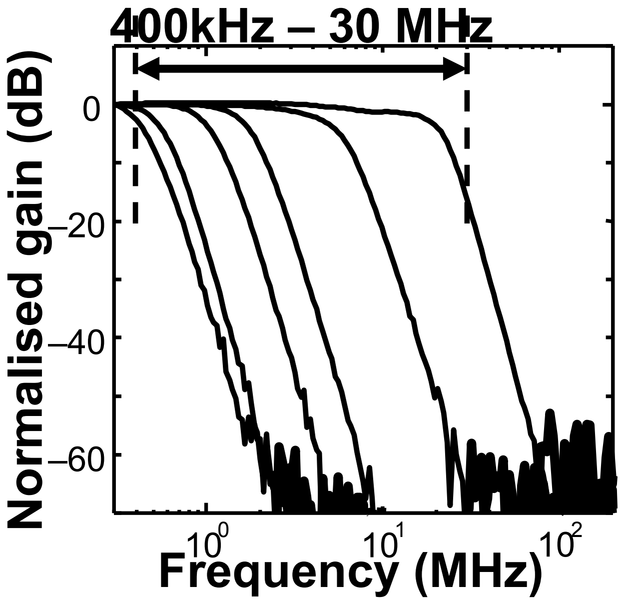


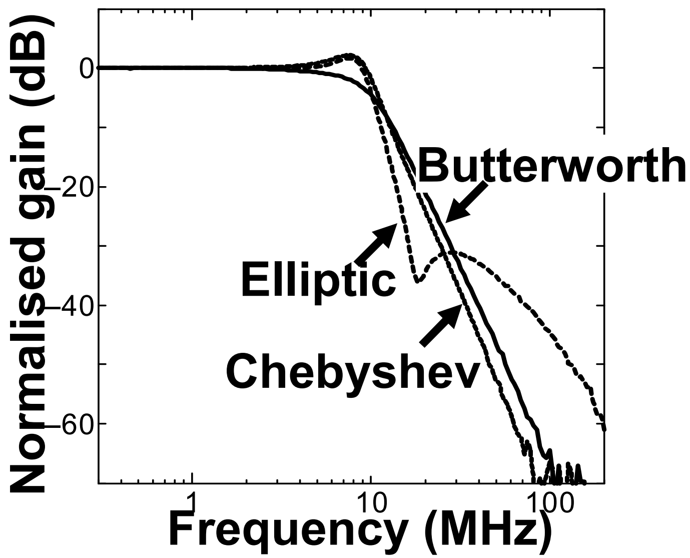
90nm CMOS process
Die area=0.57 mm^2

M. Kitsunezuka, S. Hori, and T. Maeda, "A Widely-tunable, Reconfigurable CMOS Analog Baseband IC for Software Defined Radio," *IEEE Journal of Solid-State Circuits, vol. 44, no. 9, Sept 2009*

(4-2) Frequency Response for the Developed ABB

- 1.5 times wider tuning range (400k to 30MHz) than conventional ABB
- Various filter characteristics





- ✓ Developed an analogue BB consisting of widely tuneable reconfigurable filter
- ✓ Filter characteristics can be reconfigured by controlling a pulse duty-cycle
- ✓ This result can be applied to a single RF chip to support any wireless standard.

Concluding Remarks

Concluding Remarks

- White space utilisation is one of the most effective solutions for handling exploding mobile data traffic in wireless broadband
- Dynamic spectrum access type of cognitive radio is a key enabler for the white space utilisation
- We see the Cellular Extension cognitive radio system is a promising scenario
- Enabling technologies are shown:
  - Advanced spectrum management with site-specific interference estimation and interference monitoring
  - IA-PFT interference avoidance transmission
  - MCAS spectrum sensing
  - Software Defined Radio technologies: digital baseband platform; and widely tuneable analogue filter

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