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Interference Tolerable Threshold Analysis in Cognitive Femtocells

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SEVENTH FRAMEWORK PROGRAMME

Contents

Motivation

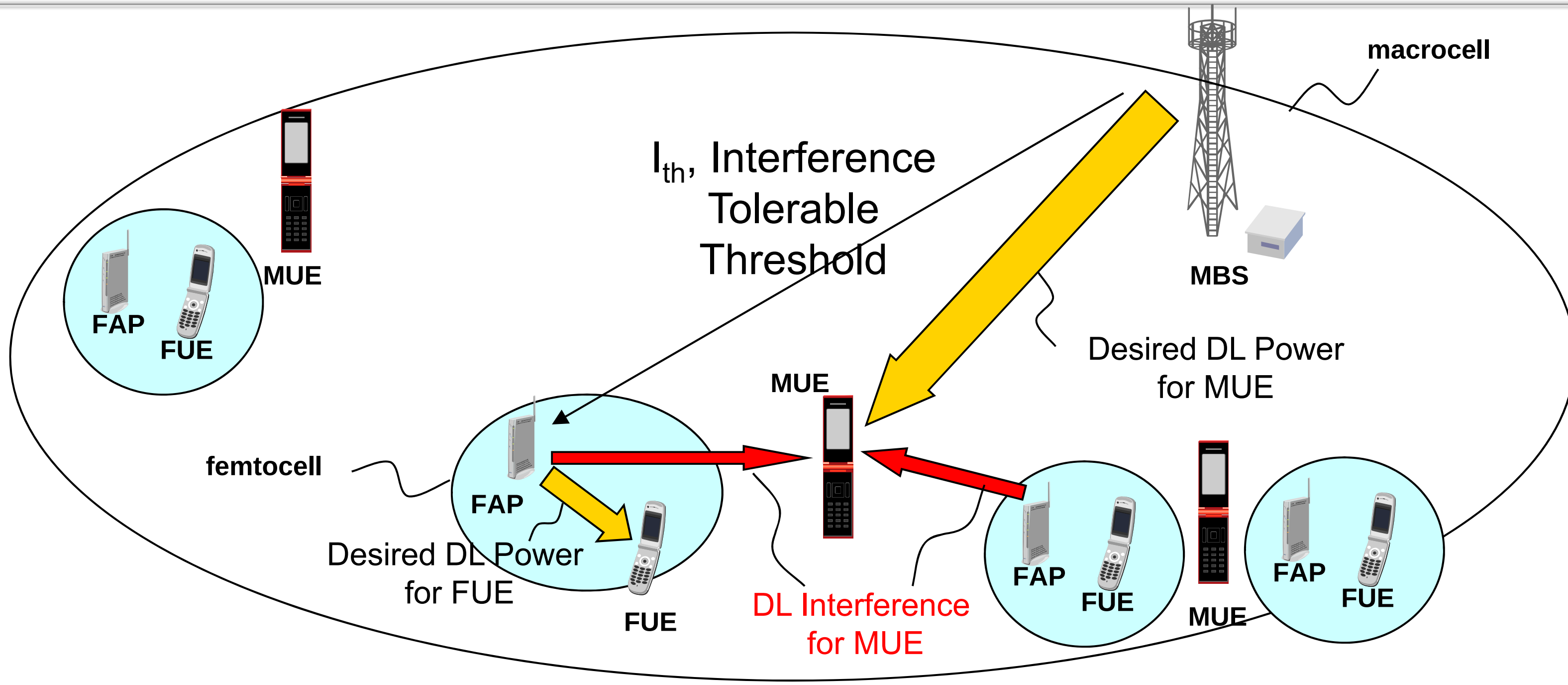
- Cognitive Radio Technology solves spectrum shortage problem by:
  - intelligent spectrum sensing
  - spectrum reuse planning
  - opportunistic spectrum allocation
  - learning the spectrum environment

- Cognitive Femtocell
  - Radio environment measurements
  - Dynamic spectrum allocations with frequency reuse
  - Interference management of co-channel deployment
  - Self organization network and Self optimization network
  - Without co-ordinated deployment with macrocell

Objectives

- Co-channel deployment of femtocell and macrocell
  - The individual interference to the macrocell users caused by one femtocell may be in an acceptable range
  - The aggregate interference from a large number of femtocells might exceed the acceptable range.
- Femtocell Throughput vs. Interference Mitigation
  - Mitigation of the aggregate interference from femtocell base stations to the macrocell user (limiting Tx power of femtocell AP)
  - Maximization of SINR for higher femtocell system throughput (maximizing Tx power of femtocell AP)
- **Interference Tolerable Threshold I_{th}** is analysed.
  - I_{th} limits the FAP Tx power to avoid the interference at macro users.

System Model



- **[Interference]** The individual and aggregate downlink interference from FAP to MUE is considered in co-channel scenario for macrocell and femtocells.
- **[Tx Power]** Each FAP will calculate the estimated individual interference at each MUE from the own FAP. FAP controls the Tx power to make the estimated individual interference lower than *Ith*.
- **[I_{th} broadcast]** No interactive communication between MBS and FAP. MBS transmits *Ith* to all FAPs by in the macrocell via a unidirectional broadcast.

Formulations (1/2)

Tx Power and Interference

Macrocell

$$\mathrm{P}^m = \left[P_1^m, P_2^m, \ldots, P_N^m\right]^{\mathrm{T}} \quad \text{(M1)}$$

Tx Power of n_{th} MUE in n_{th} channel
N: num of active MUEs

$$I_n^{fm} = \sum_k^K \frac{P_{kn}^f}{L_{kn}^{fm}} \quad \text{(M2)}$$

Interference from all FAPs to n_{th} UE
L_{kn}^{fm} : propagation loss [k_{th} FAP - n_{th} MUE]

Femtocell

$$\mathrm{P}^f = \begin{bmatrix} P_{11}^f, P_{12}^f, \ldots, P_{1N}^f \\ P_{21}^f, P_{22}^f, \ldots, P_{2N}^f \\ \vdots \quad \vdots \quad \ddots \quad \vdots \\ P_{K1}^f, P_{K2}^f, \ldots, P_{KN}^f \end{bmatrix} \quad \text{(F1)}$$

Tx Power of kth FUE in nth channel
K: num of active FUEs
N: num of channels

$$I_{kn}^{mf} = \frac{P_n^m}{L_k^{mf}}$$: Interference from nth MBS to nth channel of k_{th} FUE (F2)

$$I_{kn}^{ff} = \sum_{i=1, i \neq k}^K \frac{P_{in}^f}{L_{ik}^{ff}}$$: Interference from all FAPs to n_{th} channel of k_{th} FUE (F3)

L_k^{mf} : propagation loss [MBS - k_{th} FUE]

L_{ik}^{ff} : propagation loss [i_{th} FAP - k_{th} FUE]

Formulations (2/2)

Target SINR and Accept conditions

Macrocell

$$\frac{P_n^m}{L_n^{mm}(I_n^{fm} + P_N)} = S_n^m$$: target SINR of n_{th} MUE (M3)

L_n^{mm} : propagation loss [MBS - n_{th} MUE]

P_N : noise power

$I_n^{fm} \le \gamma_1 P_N$: MUE accept condition (M4)

γ_1 : MUE interference coefficient

$$P_n^m = S_n^m L_n^{mm}(I_n^{fm} + P_N) = S_n^m L_n^{mm} P_N (1+\gamma_1) \quad \text{(M5)}$$

Femtocell

$$\frac{P_{kn}^f}{L_{kk}^{ff}(I_{kn}^{ff} + I_{kn}^{mf} + P_N)} = S_{kn}^f$$: target SINR of n_{th} channel of k_{th} FUE (F4)

L_{kk}^{ff} : propagation loss [k_{th} FAP - k_{th} FUE]

$I_{kn}^{ff} + I_{kn}^{mf} \le \gamma_2 P_N$: FUE accept condition (F5)

γ_2 : FUE interference coefficient

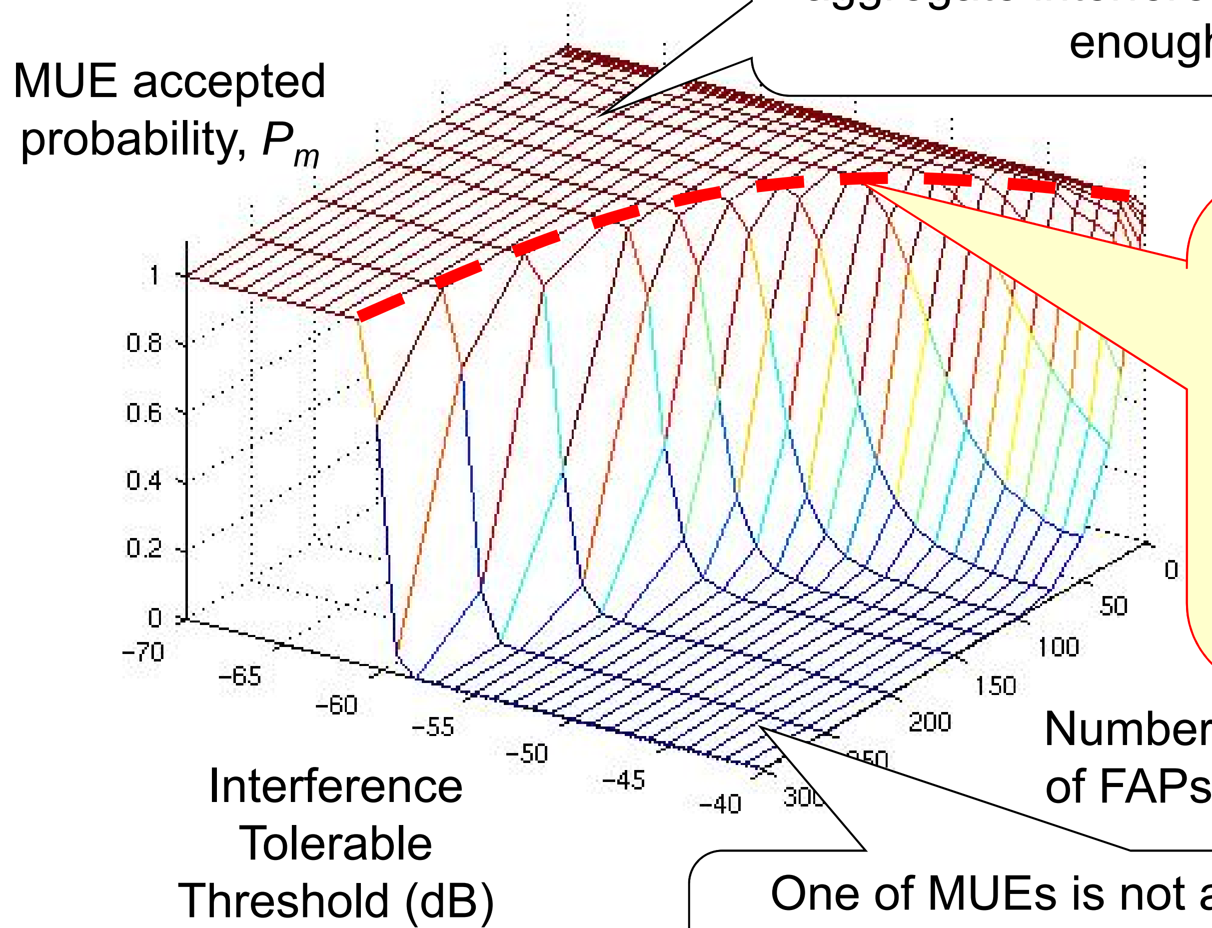
$$I_{kn}^{fm} = \frac{P_{kn}^f}{L_{kn}^{fm}} < I_{th}$$ Individual interference management (F6)

$$P_{kn}^f = \min(S_{kn}^{ff} L_{kk}^{ff}(I_{kn}^{ff} + I_{kn}^{mf} + P_N), L_{kn}^{fm} I_{th}) = \min(S_{kn}^f L_{kk}^{ff} P_N (1+\gamma_2), L_{kn}^{fm} I_{th}) \quad \text{(F7)}$$

Parameters used in Simulation Model

Parameter Name	Value	Description
Number of MUEs, *N*	8	MUEs are uniformly distributed in a macrocell.
Number of channels, *N*	8	All channels are shared by macrocell and femtocell systems.
Macrocell radius	500 [m]	MBS is located at the center of the macrocell.
Femtocell radius	10 [m]	The femtocell coverage Is not overlapped each other.
Target SINR of macrocell system, S_n^m	10 [dB]	
Target SINR of femtocell system, S_{kn}^f	10 [dB]	This value may decrease due to the FAP Tx Power limited by I_{th}.
MUE interference coefficient, γ_1	10^{-4}	-
FUE interference coefficient, γ_2	10	-
Propagation loss model, *L*	$15.3 + 37.6 \log_{10} d + \alpha L_{wall}$, L_{wall} : 15 [dB], α: number of walls	

Static Interference Tolerable Threshold Analysis (1/2)



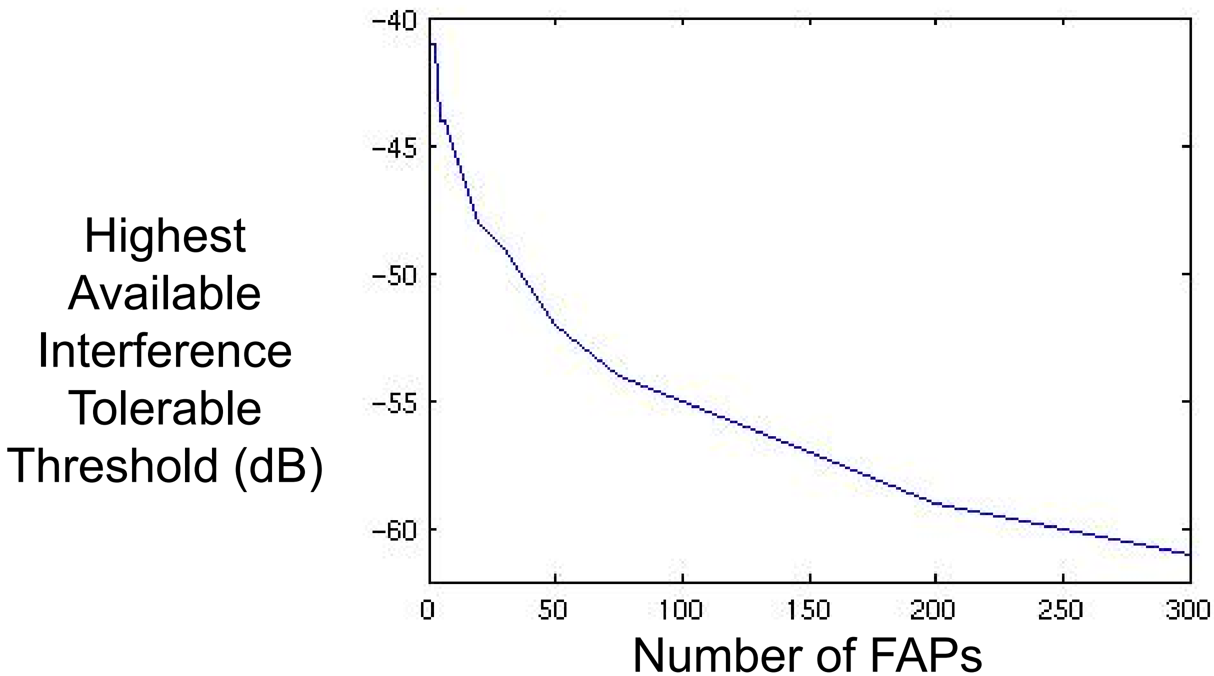
All MUEs are accepted because the aggregate interference from FAPs is small enough by low I_{th}

Highest available Interference Tolerable Threshold I_{th}

- **Guaranteeing $P_m = 1$ for MUEs**
- **Achieving the highest SINR of FAPs**

One of MUEs is not accepted because the aggregate interference from FAPs is too large by high I_{th}.

Static Interference Tolerable Threshold Analysis (2/2)



- Highest Available Interference Tolerable Threshold depends on the number of FAPs. The number of FAPs affects the aggregate interference to the MUE.
- This figure is useful for the macrocell system configuration to make the aggregate interference at MUE in acceptable range.
- New FAPs may be installed and Some of FAPs may be turned off to save its energy . Therefore, the awareness of the exact number of active FAPs is difficult.

→ Dynamic Interference Tolerable Threshold control mechanism is proposed.

Proposed Algorithm

$$I_{th}(t) = I_{th}(t-1) + \Delta I_{th} \quad \text{if} \quad I_n^{fm} \le \gamma_1 P_N \quad \text{for all N MUEs}$$

$$I_{th}(t) = I_{th}(t-1) - \Delta I_{th} \quad \text{if} \quad I_n^{fm} > \gamma_1 P_N \quad \text{for at least one MUE}$$

(D1)

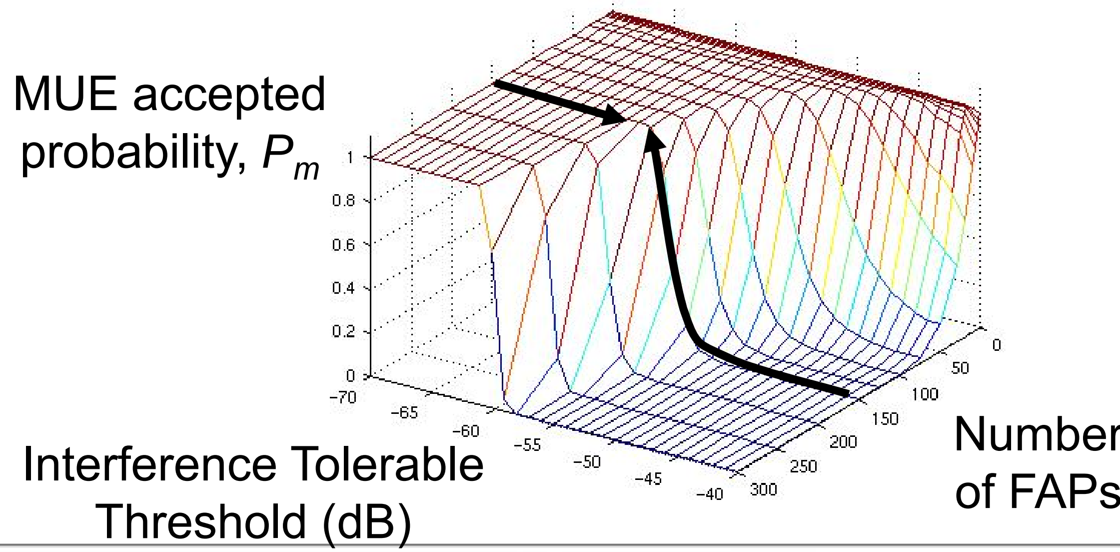
ΔI_{th} : Interference Tolerable Threshold control bit

$I_{th}(t)$ is target highest threshold in case of the following conditions:

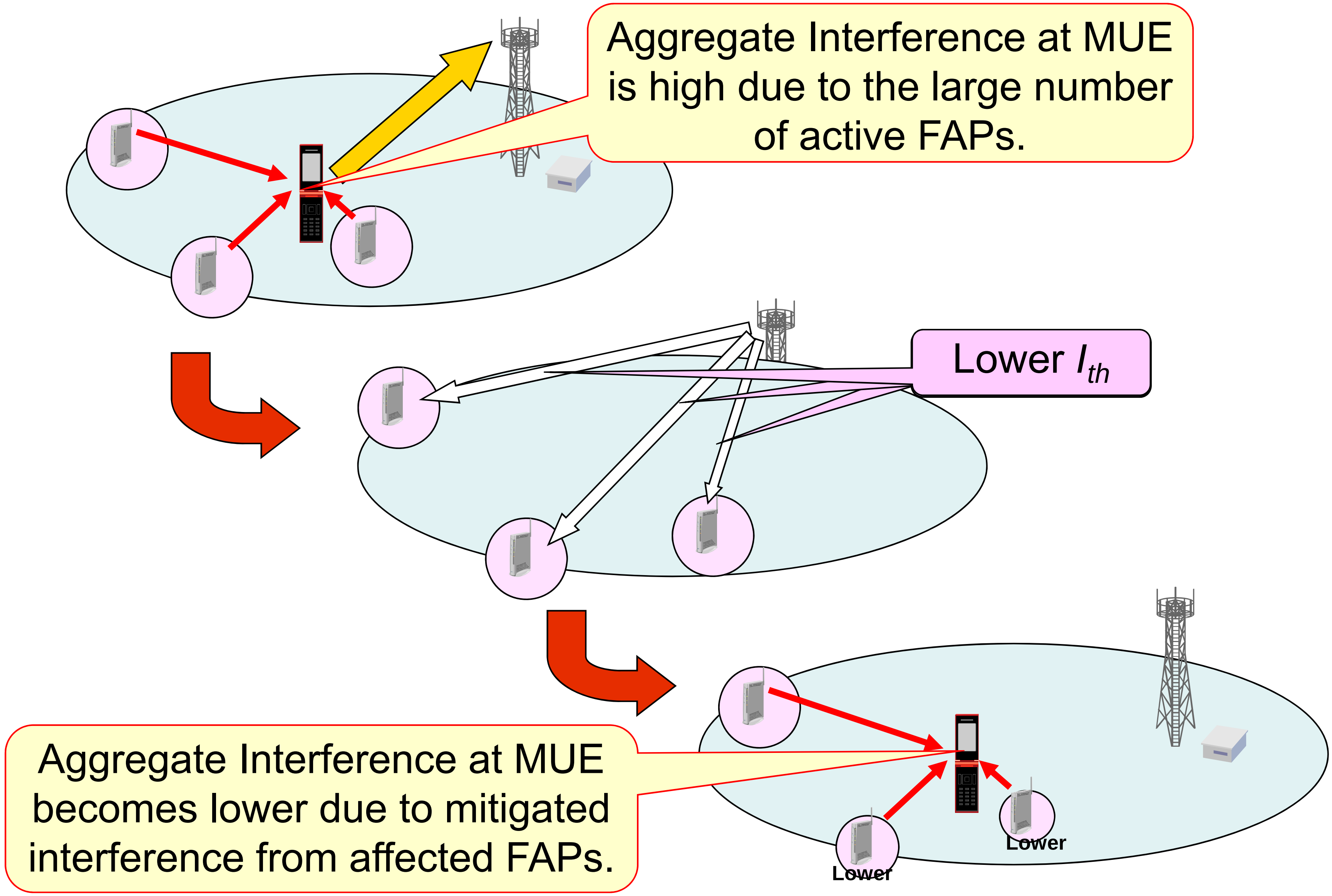
$$I_n^{fm}(t) \le \gamma_1 P_N \quad \cap \quad I_n^{fm}(t-1) > \gamma_1 P_N$$

(D2)

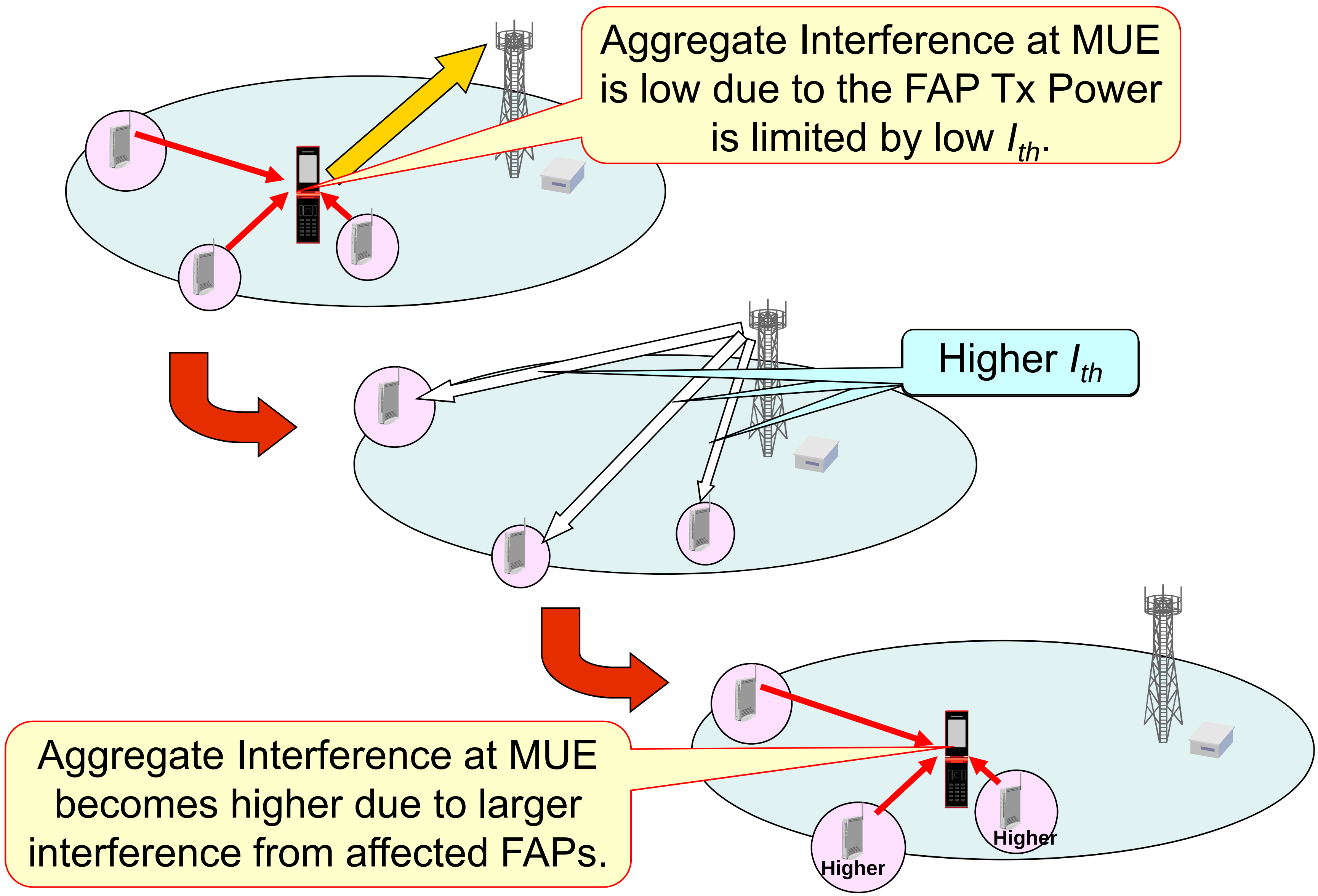
for all N MUEs — for at least one MUE



Proposed Algorithm (I_{th} decreasing)

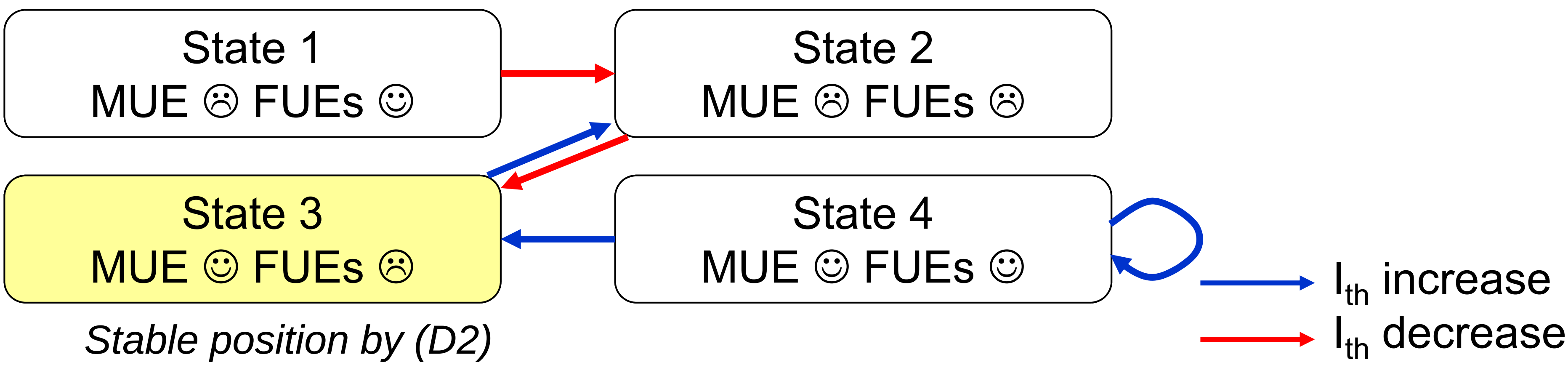


Proposed Algorithm (I_{th} increasing)



State Chart

State	Aggregate interference at MUE	Estimated individual interference from one FAP to MUE
1	$I_{kn}^{fm} > \gamma_1 \cdot P_N$ For at least one MUE	$I_{kn}^{fm} = P_{kn}^{f} / L_{kn}^{fm} < I_{th}$ For all K FUEs and all N channels
2	$I_{kn}^{fm} > \gamma_1 \cdot P_N$ For at least one MUE	$I_{kn}^{sp} = I_{th}$ For at least one channel in one FUE
3	$I_{kn}^{fm} \le \gamma_1 \cdot P_N$ For all N MUEs	$I_{kn}^{sp} = I_{th}$ For at least one channel in one FUE
4	$I_{kn}^{fm} \le \gamma_1 \cdot P_N$ For all N MUEs	$I_{kn}^{fm} = P_{kn}^{f} / L_{kn}^{fm} < I_{th}$ For all K FUEs and all N channels



Stable position by (D2)

Modified proposed algorithm

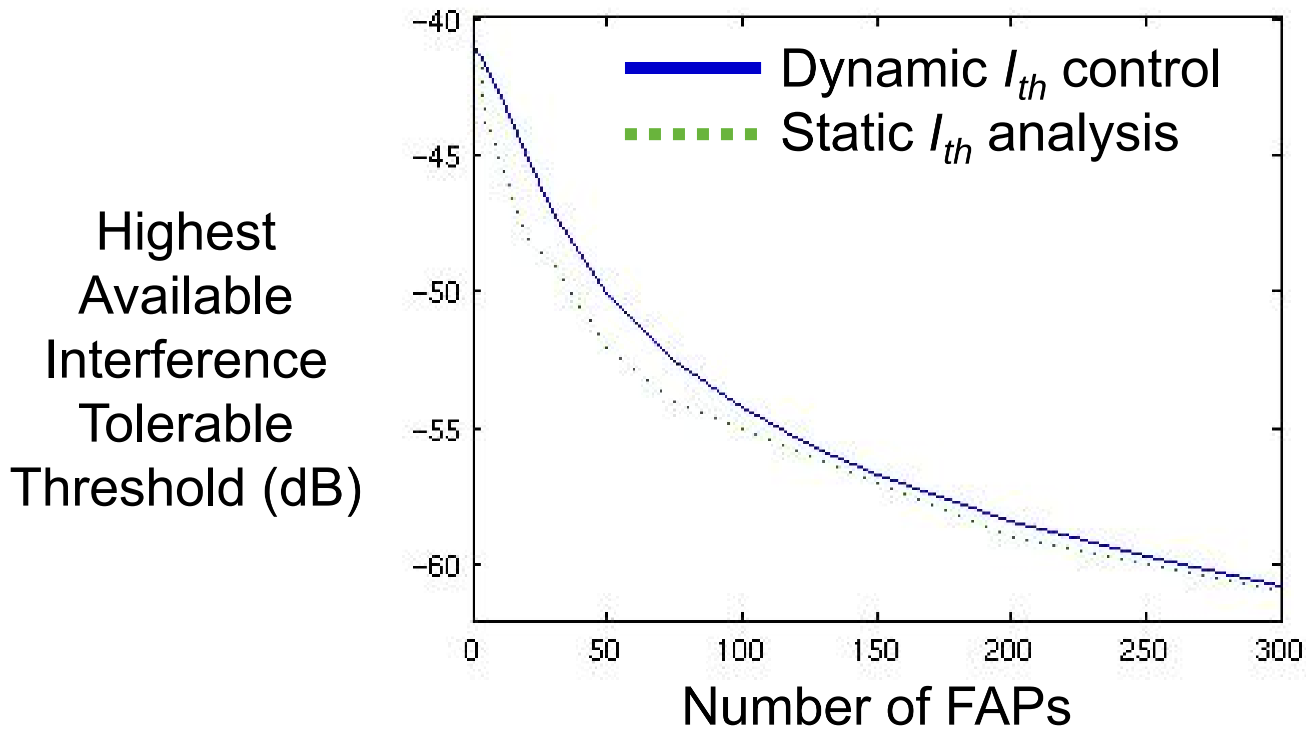
$$I_{th}(t) = I_{th}(t-1) + \Delta I_{th} \quad \text{if} \quad I_{kn}^{fm} \le \gamma_1 P_N \text{ for all N MUEs and}$$

$$I_{kn}^{fm} = I_{th} \quad \text{for at least one } n\text{th channel in one FUE}$$

$$I_{th}(t) = I_{th}(t-1) - \Delta I_{th} \quad \text{if} \quad I_{kn}^{fm} > \gamma_1 P_N \text{ for at least one MUE} \qquad \text{(D1')}$$

- Algorithm activation in State 4 can be avoided by the feedback channel from FAP to MBS (the difference).
- State 4 is only observed only when the number of FAPs is small enough and interference free scenario.
- As the alternative simple solution, range definition of *Ith* can avoid this new part.

Dynamic Interference Tolerable Threshold Control



- The result of the dynamic control scheme is similar to the static analysis.

Dynamic control scheme has a good benefit because it doesn't need the aware of number of FAPs. Even if the number of FAPs changes dynamically, the proposed scheme can adapt *Ith* to the appropriate value for active FAPs.

Conclusion and Future work

Conclusion

- Highest available interference tolerable threshold depends on the number of femtocell access points.
- In the proposed scheme, Interference Tolerable Threshold is well controlled and the adaptation of highest available value is possible without needing knowledge about the number of femtocell access points in the vicinity of MUEs.

Future Works

- More flexible Interference Tolerable Threshold, e.g., I_{th} per channel resource used by macrocell user equipment.
- Integration with more realistic scenarios is necessary.
  - Multiple spectrum allocation with additional decision to select the spectrum
  - Multiple macro cell environment with macrocell Tx Power Control and inter-macrocell interference.
  - Practical propagation model by user mobility, fading and shadowing.

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