CAN “DUMB” BEAT “SMART”?

ON ACCESS CHANNEL DESIGN FOR MOBILE IOT

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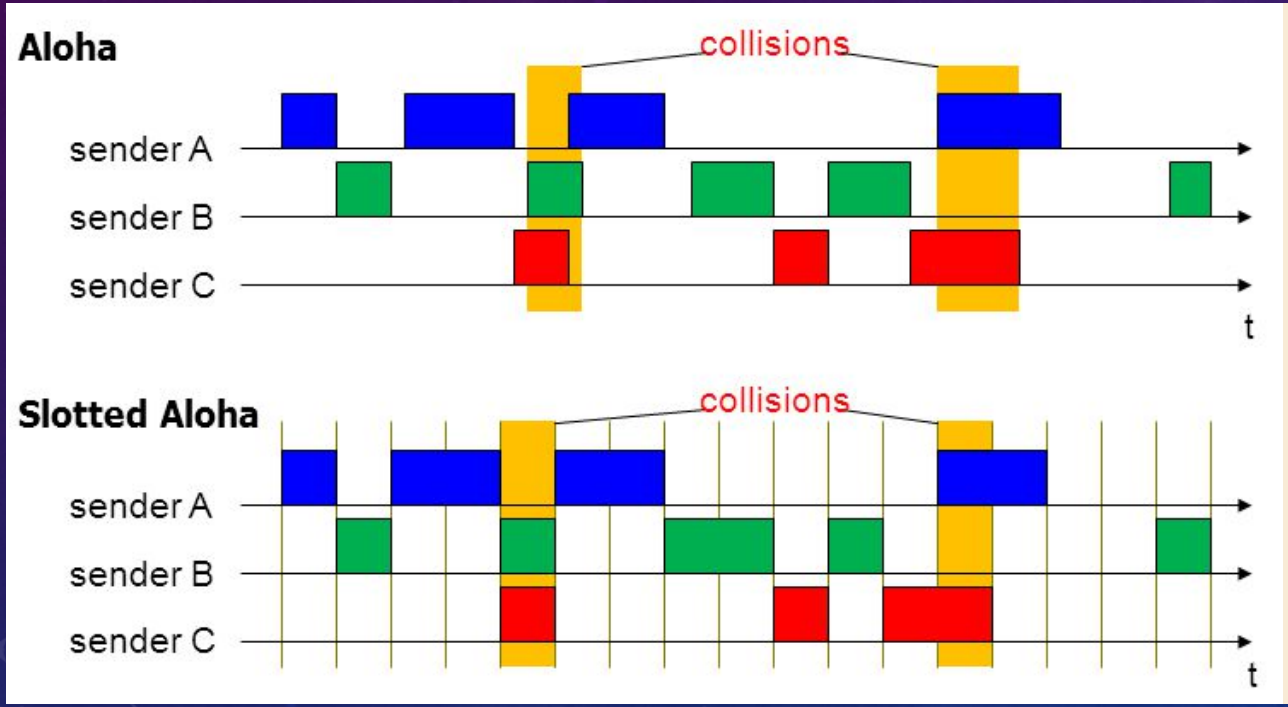
SUMMARY

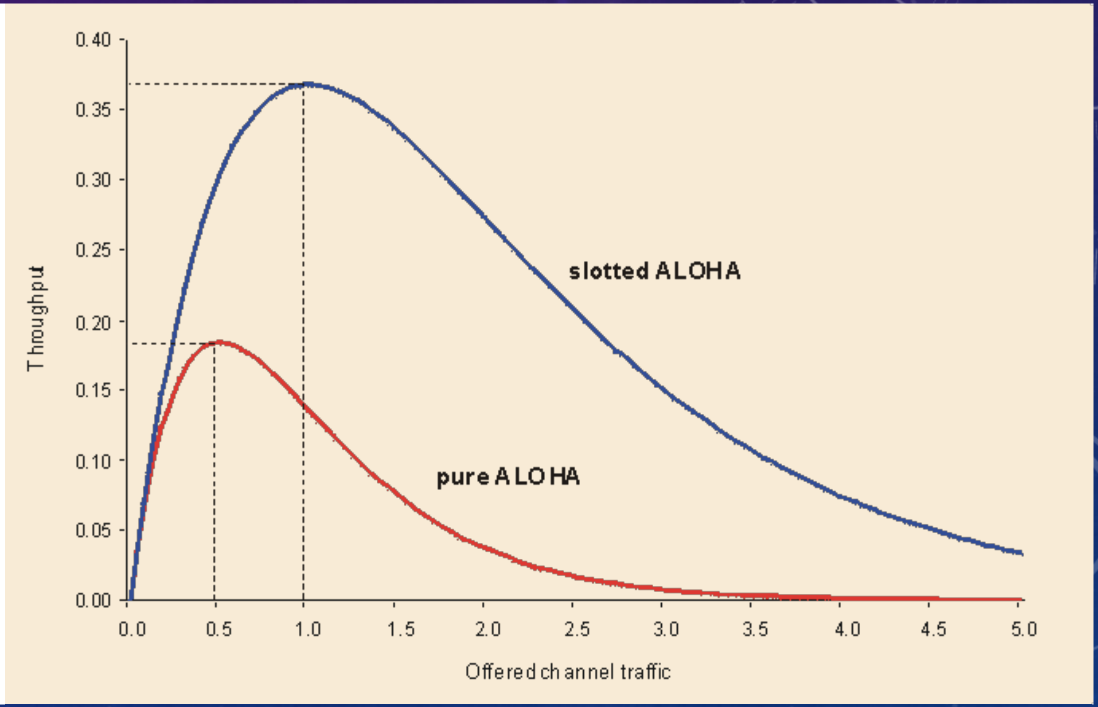
1. **Due to the signal processing limitation, traditionally access channel user capacity or throughput capacity is viewed as a function of timing (or Smartness I) and power control (or Smartness II)**
   - Aloha vs. Slotted Aloha
   - From an information-theory perspective, the optimal channel capacity is achievable through power control (Smartness II) and interference cancellation,
     - Perfect timing information may not be necessary.
2. **The proposed approach is to achieve the optimal channel capacity through**
   - Extended low power access or transmission
   - Early termination

OUTLINE

- Background
  - Aloha access channel model
  - Mobile IoT (internet of things)
- What Are The Problems?
  - IoT’s impact to existing mobile networks
  - Access success rate
- Optimal Solutions :
  - Smart & Short Access Probe
  - Dumb & Long Access Probe.
- Other considerations.

BACKGROUND (1/3): ALOHA CHANNEL MODEL





BACKGROUND (2/3): INTERNET OF THINGS (IOT)

City	Population	Area (km^2)	Area (mi^2)	Density ($/km^2$)	Density ($/mi^2$)	Country
Manila	1,652,171[1]	38.55[2]	16.55	43,079[2]	107,561	Philippines
Ebeye	15,000	0.362	0.140	41,436	107,143	Marshall Islands
Pateros *(Municipality)*	64,147[1]	2.10[3]	0.81	30,546	79,114	Philippines
Mumbai	12,478,447[4]	437.71[5]	169	28,508	73,837	India
Dhaka	8,523,137[6]	300.0[7]	115.83	28,410	73,583	Bangladesh
Bnei Brak	200,162[8]	7.088	2.736[9]	28,240	73,159	Israel
Caloocan	1,489,040[1]	53.34[3]	20.6	27,916	72,302	Philippines
Levallois-Perret	63,436[10]	2.4[10]	0.93	26,432	68,458	France
Le Pré-Saint-Gervais	18,121[11]	0.7[11]	0.27	25,887	67,047	France
Chennai	4,681,087[4]	181.06[12]	69.91	25,854	66,961	India
Vincennes	48,689[13]	1.9[13]	0.733	25,626	66,371	France
Saint-Mandé	22,627[14]	0.9[14]	0.35	25,141	65,115	France
Bally	291,972[4]	11.81[15]	4.56	24,722	64,031	India
Kolkata	4,486,679[4]	185[16]	71.4	24,252	62,813	India
Saint-Josse-ten-Noode	27,548[17]	1.14[18]	0.44	24,165	62,404	Belgium
Kathmandu	1,183,000[19]	49.45[20]	19.09	23,923	61,972	Nepal
Subang Jaya	1,683,589[21]	70.41	43.75	23,911	38,482	Malaysia
Neapoli	27,084[21]	1.17	0.45	23,188	60,186	Greece
Montrouge	48,410[22]	2.1[22]	0.81	23,052	59,705	France
Malé	133,412[23]	5.8[24][25]	2.24	23,002	59,559	Maldives

- IoT networks are expected to connect billions of devices in the next several years.
  - One ambitious 5G requirement is to serve massive Internet of Things (IoT).
- Obviously these requirements are highly expected for the IoT networks operated in high population density cities, where a large portion of IoT end-devices will be deployed.
  - For example, as shown in the table below, the population density in Chennai, India is 25,854 per Km^2.
  - If in average it is assumed that **one IoT device per capita** and the coverage of one IoT base station is 4 Km in radius, the number of the served IoT devices per base station is expected to be 25,854 x 3.14 x 16 = 1,298,905.
  - This means, considering a 30-minute period and assuming that there is no retransmission in a 4 km IoT network deployed in Chennai, India, the expected access capacity is 1,298,905 access per 30 minutes.

BACKGROUND (2/3): MOBILE IOT

Characteristics	LoRaWAN	C-UNB	EC-GSM	LTE Cat-0	LTE Cat-M	LTE Cat-M1	NB-IoT
Evolution Path	Clean Slate	Clean Slate	GERAN Evolution	EUTRAN Evolution	EUTRAN Evolution	EUTRAN Evolution	EUTRAN Evolution
UL System Bandwidth	125kHz x N	160Hz x N	1.4MHz	1.4MHz - 20MHz	1.4MHz - 20MHz	1.4MHz	180kHz x N
UL Channel Bandwidth	125kHz	100 Hz	180 kHz	1.08 MHz	1.08 MHz	1.08 MHz	3.75kHz or 15kHz
Multiplexing Scheme		FDMA	TDMA	OFDMA	OFDMA	OFDMA	FDMA or SC-FDMA
Preamble Modulation	Chirp spread spectrum	GFSK	GMSK or 8PSK	SC-FDMA	SC-FDMA	SC-FDMA	single-tone
Mini. Preamble Length	172 ms, 5 symbols			3 ms	3 ms	3 ms	3 ms
Data Payload Modulation	Chirp spread spectrum	GFSK	GMSK or 8PSK	QPSK, 16QAM, 64QAM	QPSK, 16QAM, 64QAM	16QAM	BPSK or QPSK
Data Payload Coding	16-bit CRC				Turbo	Turbo	Turbo
Mini. Payload Length	262 ms, 1 byte	7-25 bytes					
Max Output Power	20 dBm	24 dBm	23/33 dBm	23 dBm	20/23 dBm	20/23 dBm	20/23 dBm
Data Rate	290bps~50kbps	100 bps	10kbps~240kbps	1 Mbps	1 Mbps	150 kbps	250 kbps
Maximum Coupling	154 dB	164 dB	164 dB	140 dB	155 dB	155 dB	164 dB
Initial Access Schemes	Pure Aloha	Slotted Aloha	Slotted Aloha	Multi-Stage Slotted Aloha	Multi-Stage Slotted Aloha	Multi-Stage Slotted Aloha	Slotted Aloha
Open-Loop Power	No		Yes	Yes	Yes	Yes	Yes
Macro Spatial Diversity		Cooperative Selection	No	No	No	No	No
Mobility	Nomadic	Nomadic	Full	Full	Full	Full	Nomadic

THE PROBLEMS

- #1 issue for mobile system upgrade is how to minimize the impact on the existing network services when IoT terminals increase.
  - **Channelization**: minimize the overlapping between legacy probes and IoT probes
  - **Power Control**: minimize the interference to legacy 1x services.
  - #2 issue is to improve IoT terminals access success rate, which doesn't always conflict with Issue #1.
- The challenges to the existing mobile networks are
  - RoT (Rise over Thermal) increase: the RoT contribution from IoT terminals
  - Interference/collision: the potential dimension limit of current UL channels.
- Other related problems are
  - The macro-diversity and detection complexity dilemma
  - The network imbalance.
  - The load and throughput dilemma
- Additional considerations are
  - Improve terminal battery life.
  - Improve network Positioning.

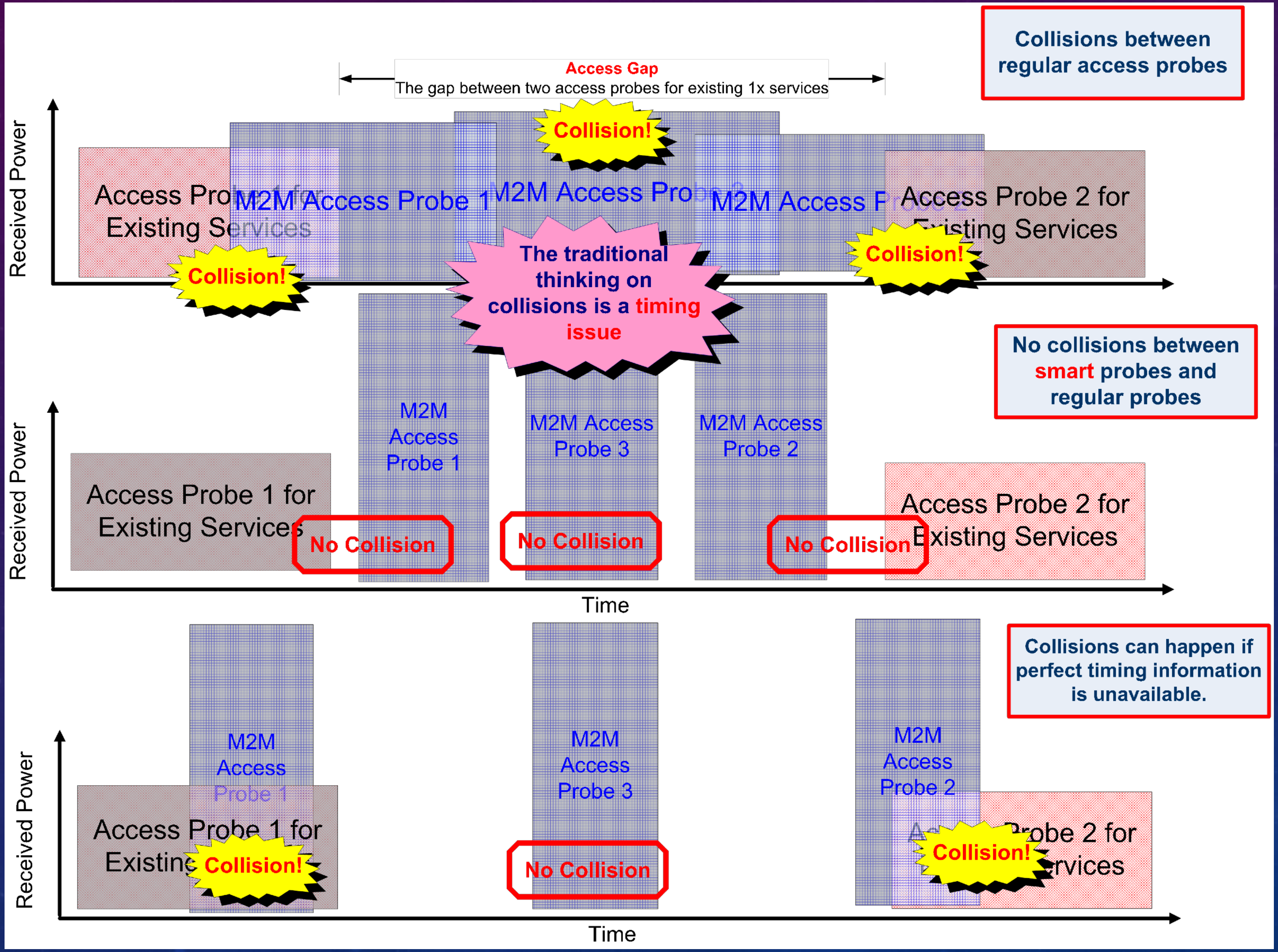
ANSWERS TO ISSUE #1 (1/2): DUMB VS. SMART

- **Two Completely Different Answers: Dumb *vs.* Smart.**
  1. **Very SMART & SHORT access probe.**
     - "Smart" means the probe knows the access timing of others.
       - It always arrives inside some access gap and has little overlap with existing access probes.
     - In order to be smarter, an access probe need be shorter.
       - A short access length means high Tx power and data rate.
  2. **Very DUMB & LONG access probe.**
     - "Dumb" means it has no timing information of other probes.
     - For exploring access gaps, each probe is very long instead.
       - Long probe usually means low Tx power, low data rate and more diversity opportunities possible.
     - Low data rate means more redundancy and protection.
       - Coding gain and processing gain v.s. Tx Power
- **Two Different Views: Power Control *vs.* Timing.**
  - For smart probes, timing information is the challenge and key.
  - For dumb probes, power control is the key.

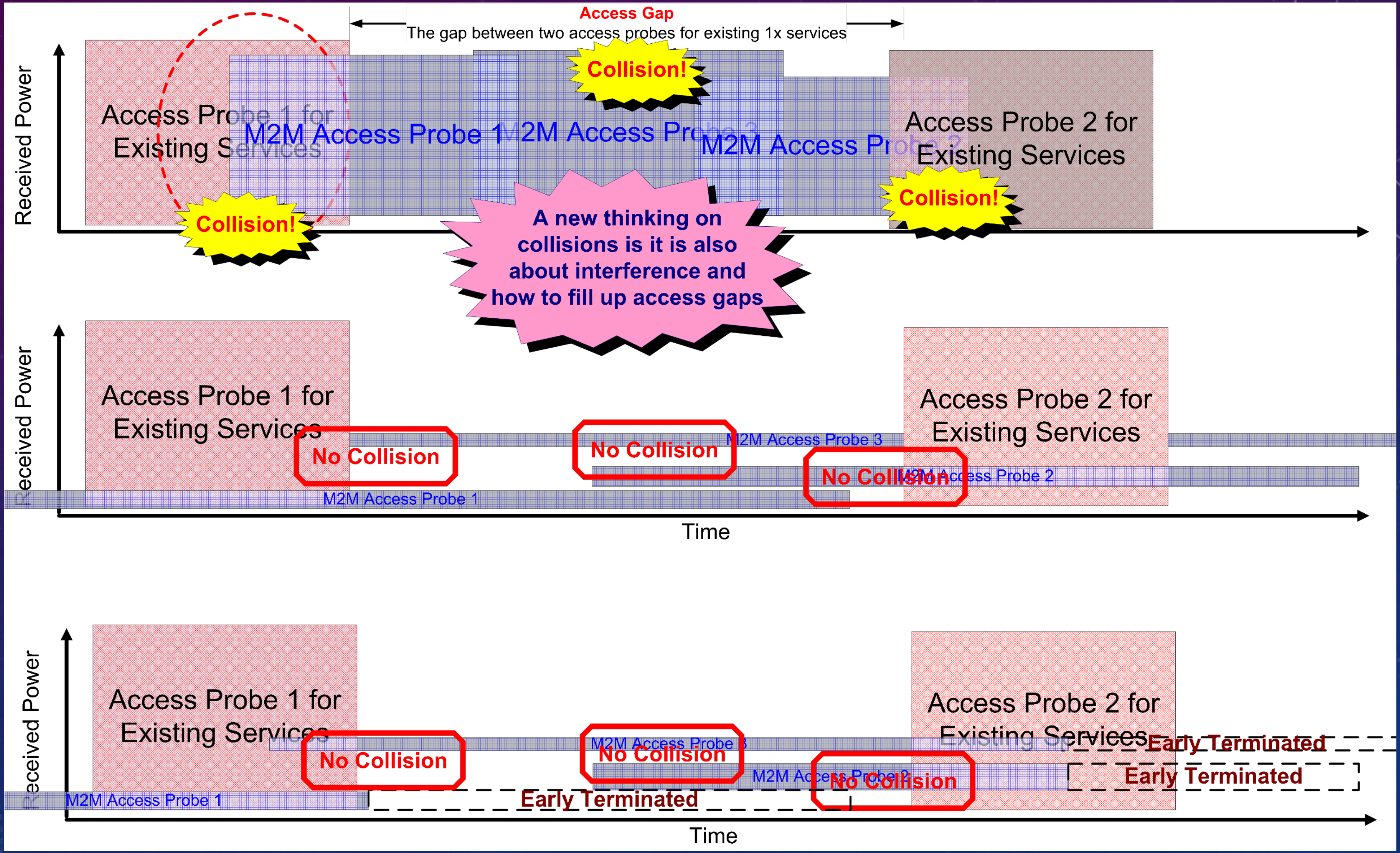
ANSWERS TO ISSUE #1 (1/2): COMPARISON

	Smart Access Probe	Dumb Access Probe	Comments
Require perfect access Timing of other terminals	Yes	No	Different design starting points.
Require power control	No	Yes	
Require early termination	No	Yes	
Tx Power and Rate Requirement	High Power and High Rate	Low Power and Low Rate	
Coding & Processing Gain	Low	High	
Interference Contribution	Strong and short period	Low and long period	
RoT Contribution	Short period	Long period	
Time Diversity Gain	low	High	including channel time diversity, imperfect OL-PC, and interference fluctuation, etc.
Implementation	• The "smart" part is hard to be implemented. • The "short" part is easy to be implemented	Friendly & Easy	

TRADITIONAL THINKING OF COLLISION AVOIDANCE



A NEW THINKING OF COLLISION AVOIDANCE



EARLY TERMINATION ON LONG PROBES

- It is possible for an AP to successfully detect and decode dumb access probes much earlier before a IoT terminal finishes it transmission, due to
  - Imperfect Open-Loop Power Control.
  - Interference / RoT Fluctuation.
  - Channel Time Diversity
- As soon as a BS successfully decodes one dumb access probe, it will send ACK in the earliest next paging cycle.
- As soon as a IoT terminal successful receives ACK, it will immediately stop the transmission of the rest probe.
- Early termination is possible due to the duration of dumb access probes can be more than one paging cycle.

MACRO-DIVERSITY ON LONG PROBES

- For achieving macro-diversity or soft handoff on RL access probe detection, more than one sectors will simultaneously monitor access probes.
- As soon as one sector successfully detects one dumb access probe, it will
  - Report the access header and payload data to the serving BSC/PCF.
  - (optional) send ACK through its own paging channel.
- If the terminal is monitoring the paging channels of both its serving and neighbor sectors, it will stop the transmission as soon as it receives an ACK through any forward link paging channel it monitors.
  - Due to network imbalance, it is possible that one of its neighbor sectors can successfully detect access probes much earlier than its serving sector.
- Additional macro-diversity capability helps increase early termination granularity.

SO … WHAT ABOUT CONCERN #2 ?

- Issue #2: will a long and low power access probe design have a low access success rate?
- Answer: NO.
  - ALOHA model suggests two things fundamentally affect access success rates
    - The Channel. e.g. path-loss, fading, timing and related protocols.
    - The Signal. e.g. power control, coding and modulation.
  - Access success rate is NOT determined by probe length.
  - Accurate timing information is hardly available.
  - Power control plays a key role in access channel performance.
    - Early termination is a well-understood and practical way for compensating imperfect power control.