Spatial Clustering in Slotted ALOHA Two-Hop Random Access for Machine Type Communication

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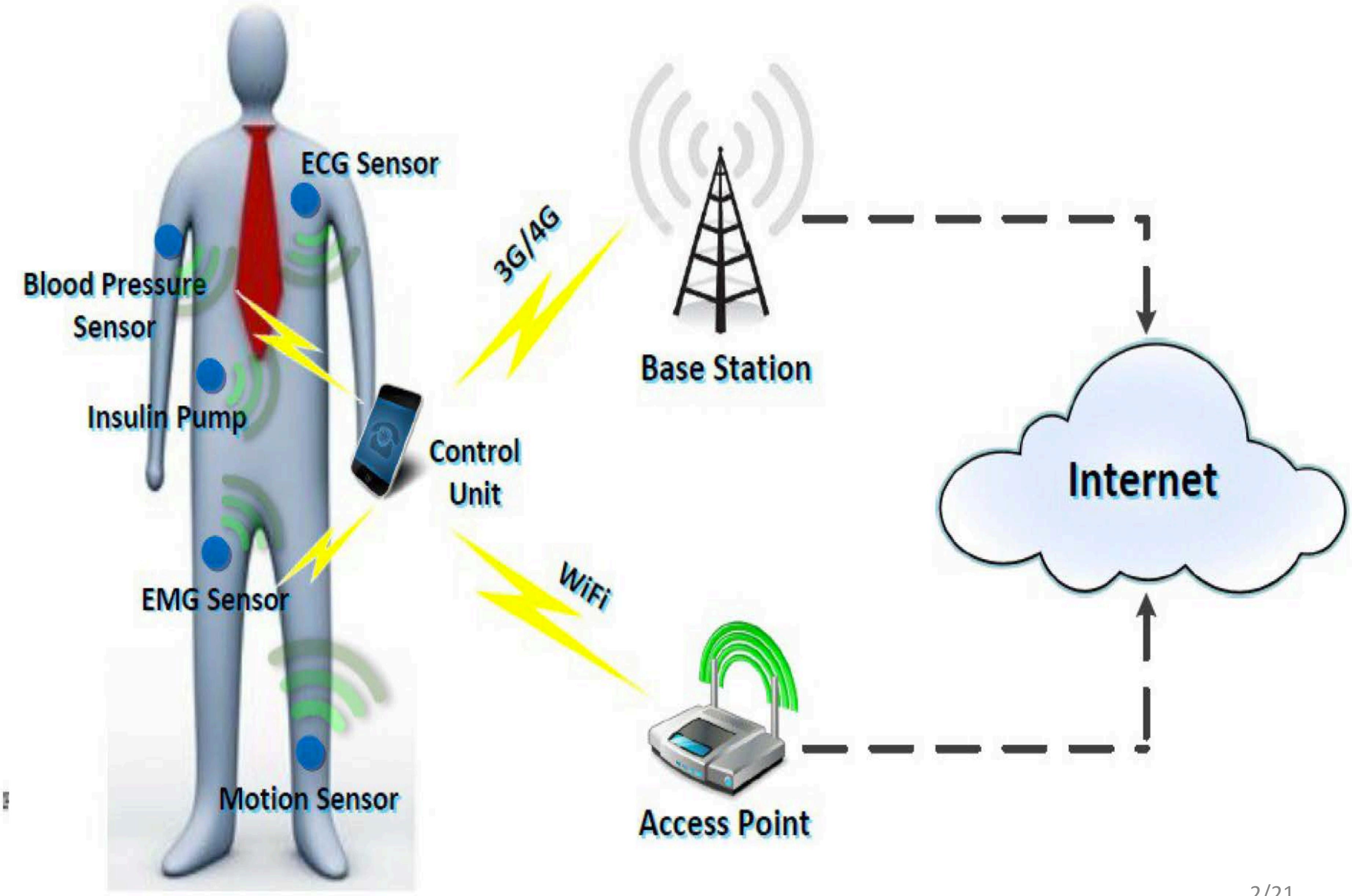
Contents

Introduction to MTC

MTC is a fully automatic communication system between machine devices without necessary human intervention.

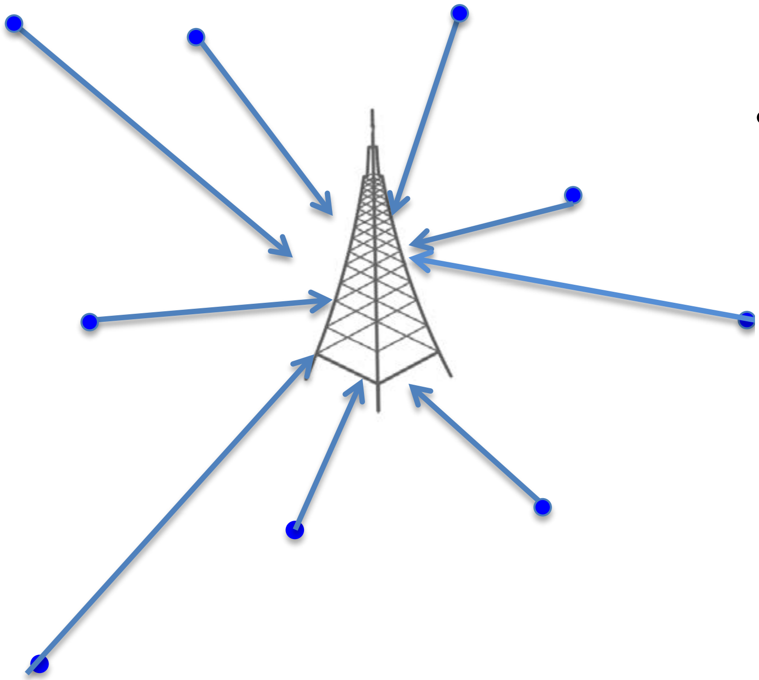
- A large number of terminals
- Small data transmissions.
- Low mobility
- Delay tolerance
- Spatially clustered

Applications [illegible]

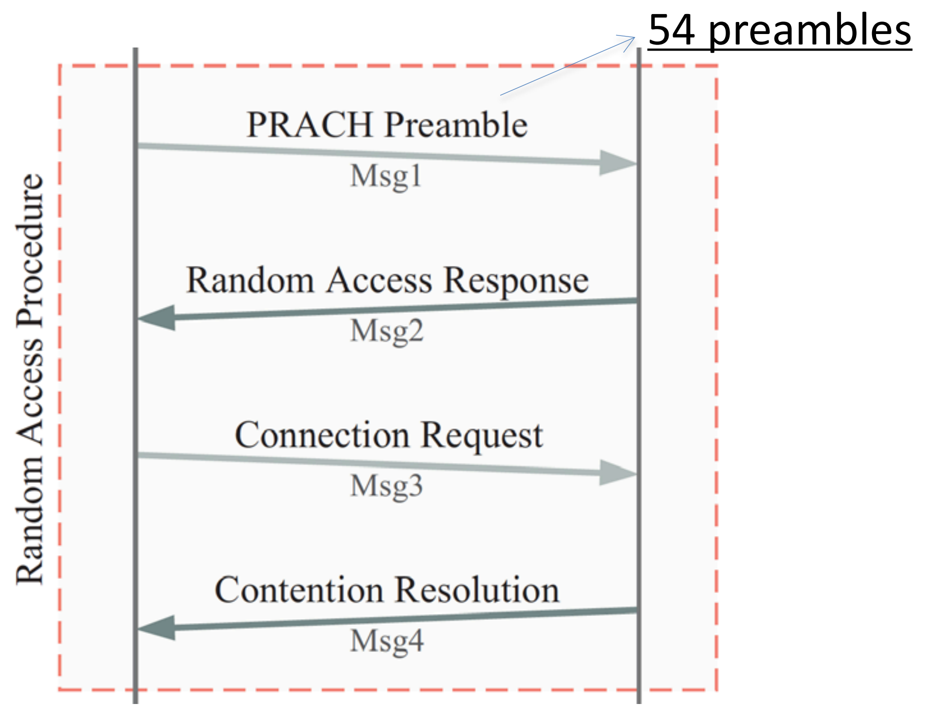


LTE Access

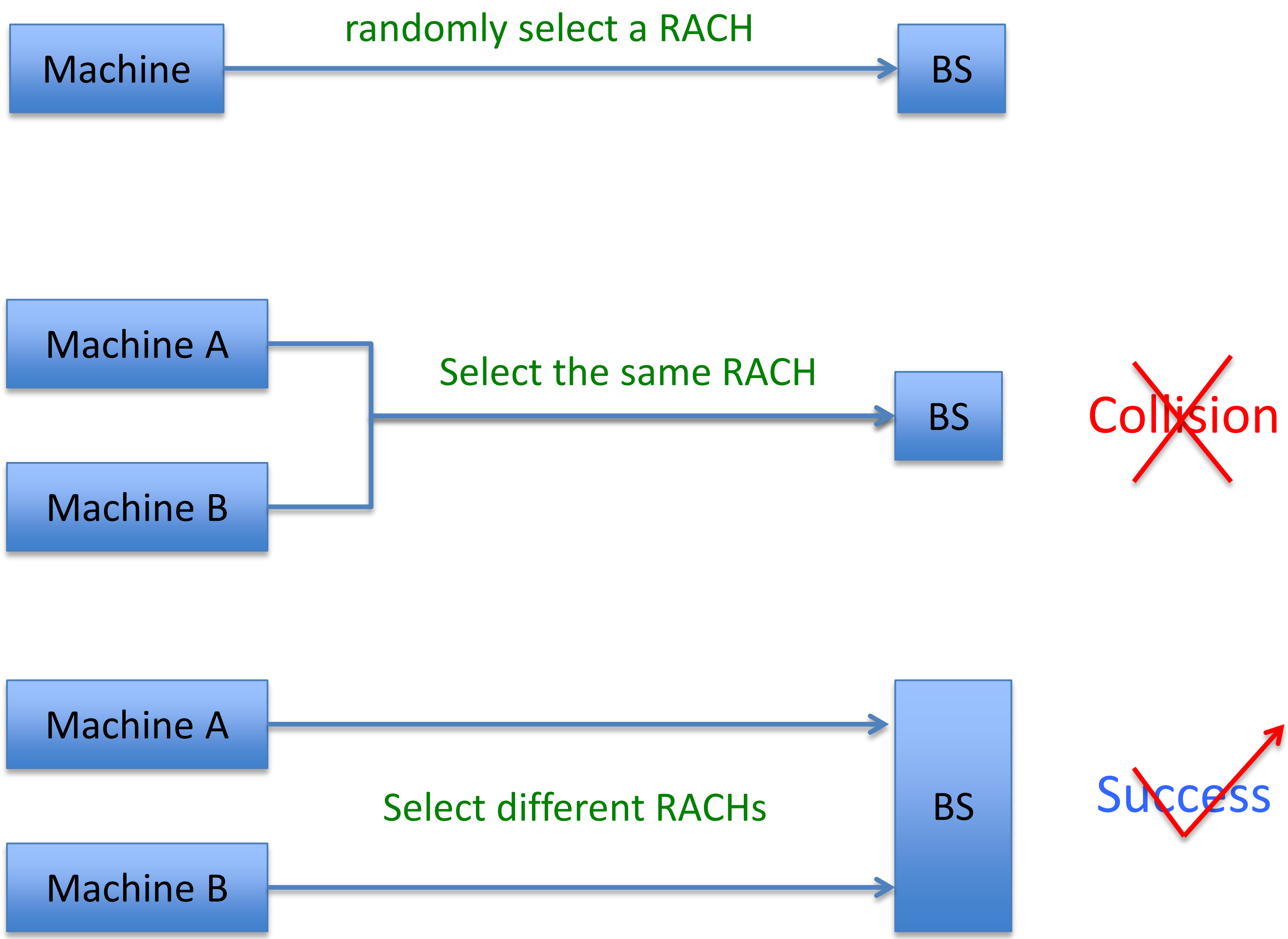
Reference Scheme



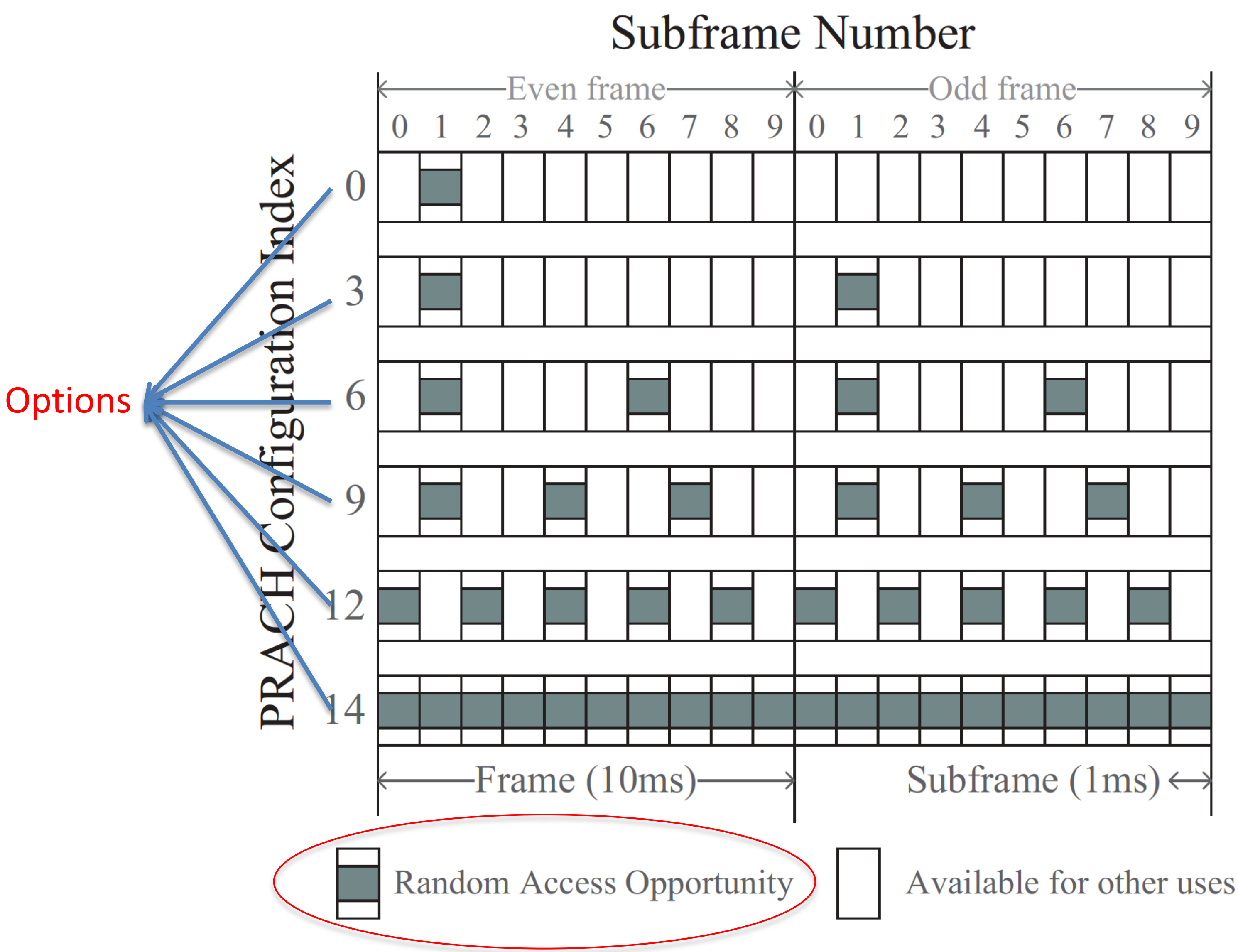
- LTE Network
- All machines directly access BS through physical random access channel (PRACH)
- Four message exchange



Random Access Channel (RACH) Model

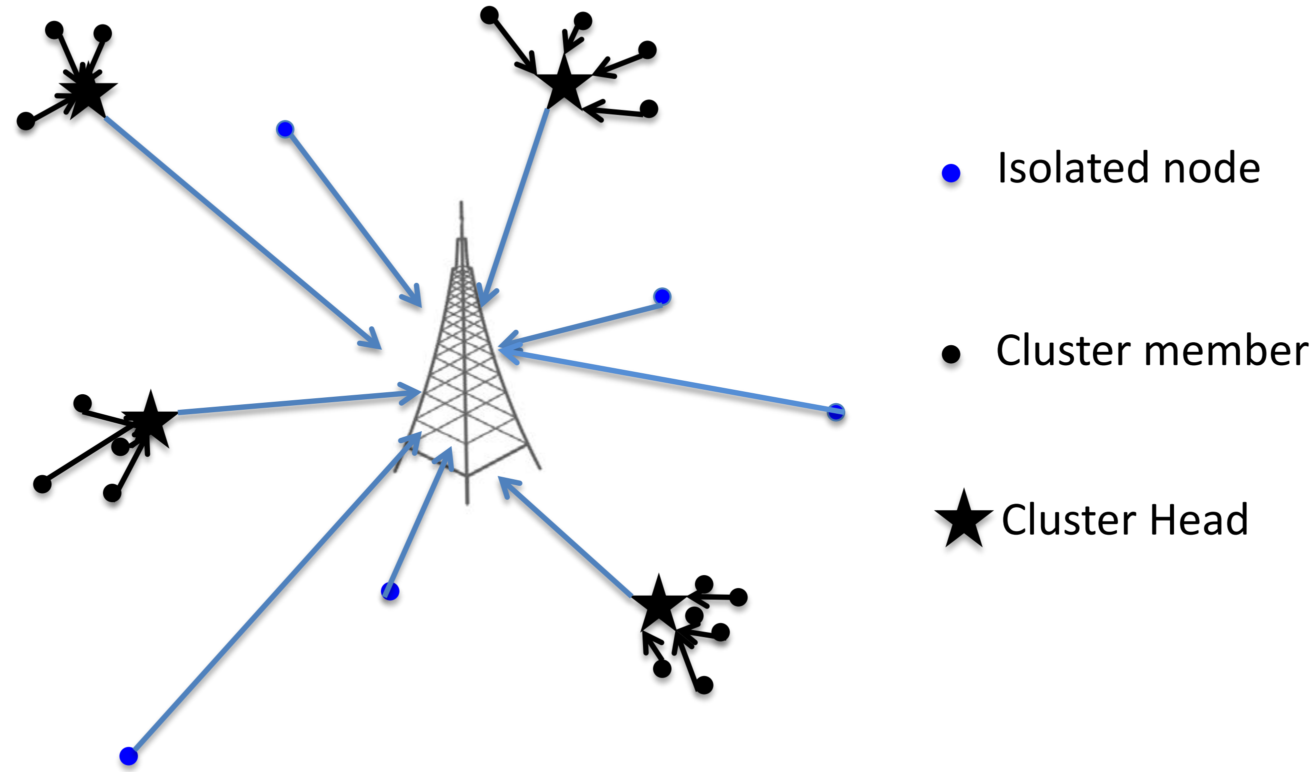


PRACH Configuration



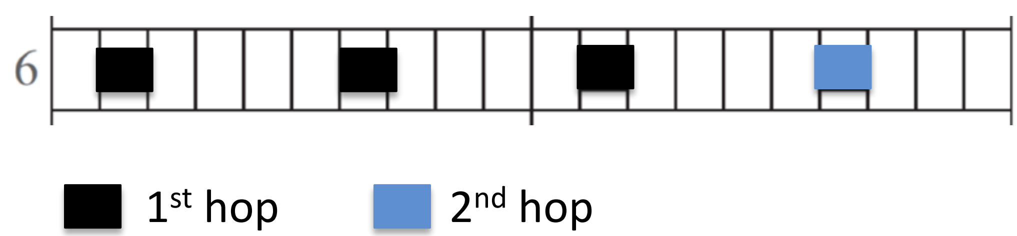
Contribution

Two-Hop Slotted ALOHA-based Clustering Scheme



- Resource allocation between slotted ALOHA (1st hop) and PRACH (2nd hop)

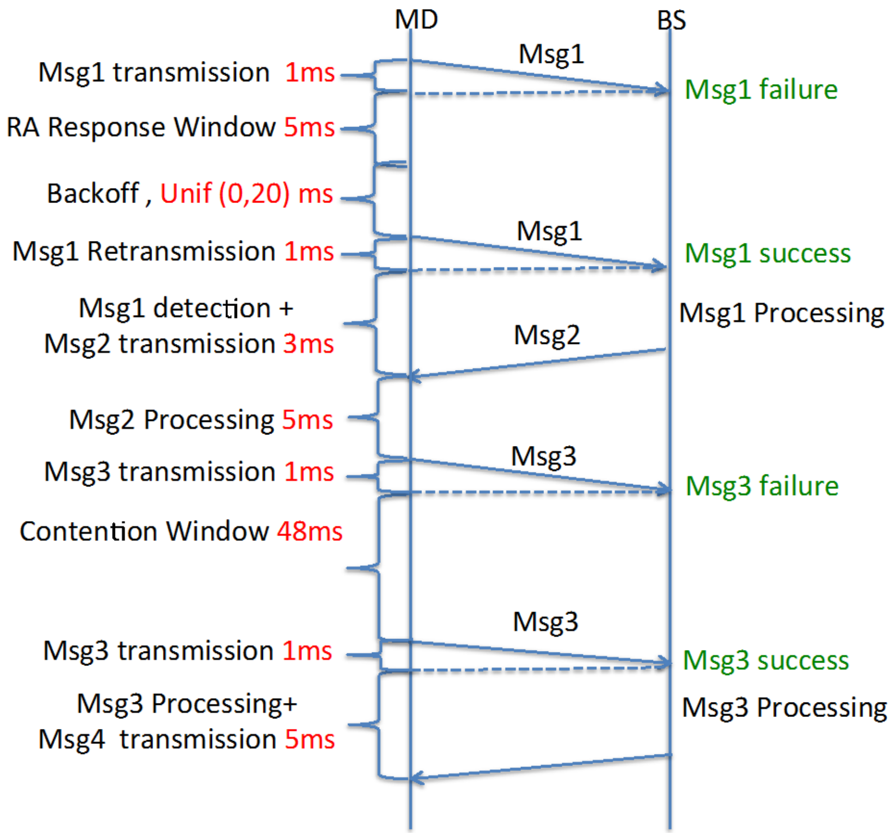
e.g. 3:1



- In each cluster, it fully reuse the resources for slotted ALOHA communication.

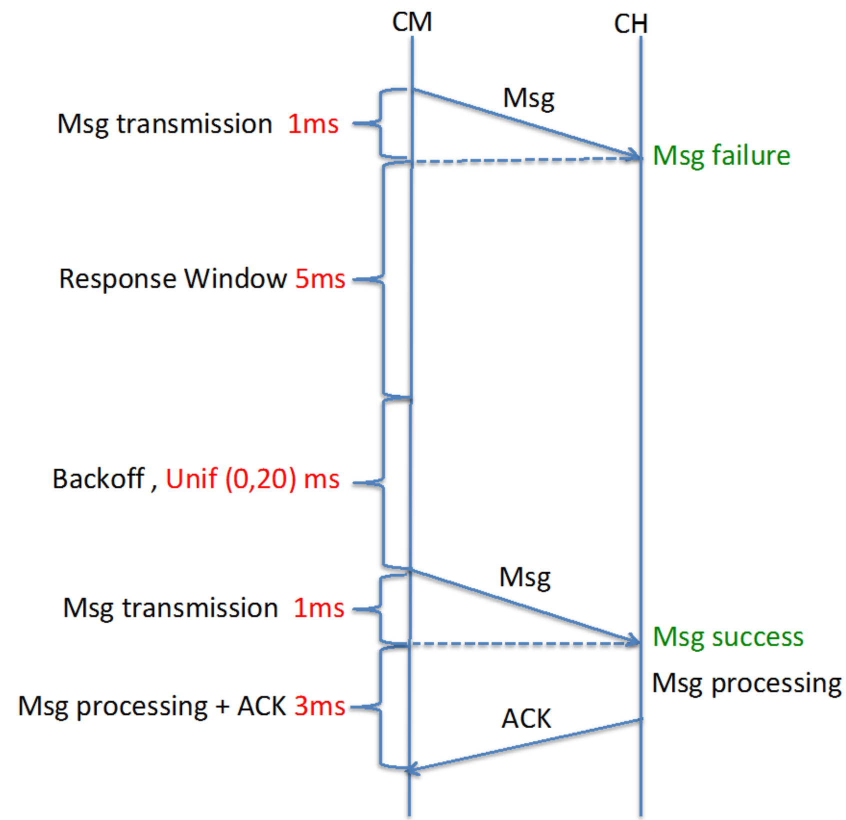
Interference inside and outside the cluster.

Details of the Access Procedures



(a) Random Access procedure.
The situation when Msg 1 and Msg 3 only have one collision.

(Reference Scheme)



(b) Slotted Aloha procedure.
The situation when only one collision occurs.

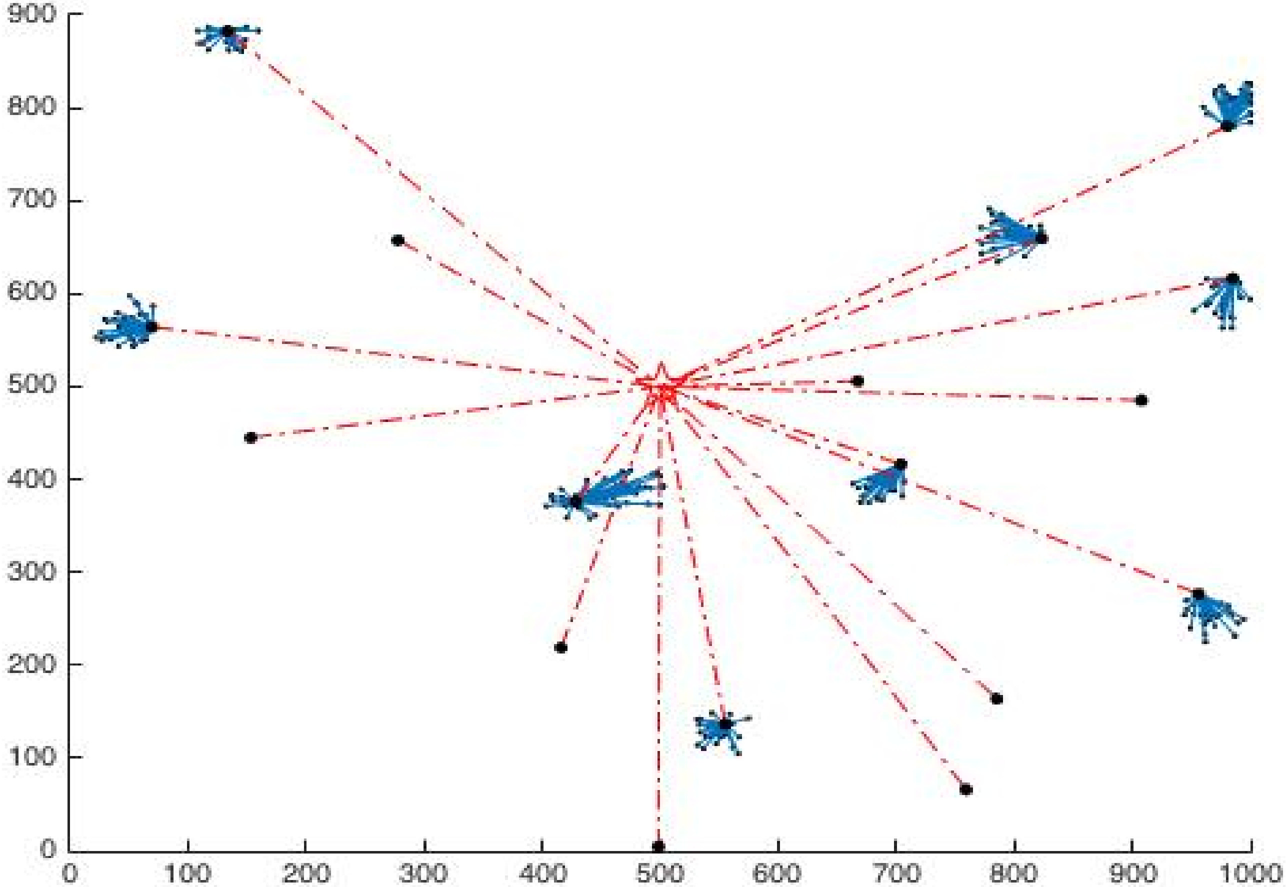
(Proposed Scheme)

Novelty

	Previous Research	Our Research
Intra-Cluster Communication Method	Scheduled Scheme (e.g. TDMA)	Slotted ALOHA
Resources for Intra-Cluster Communication	Unlicensed Resource (WiFi, ZigBee)	Resources are migrated from PRACH, All-licensed spectrum
Spatial Traffic Pattern	Homogeneous (PPP)	Clustered

System Model

Location Generator



Internal Parameters: number of devices (N), number of clusters (M), radius of cluster (R), prob. of isolated nodes ($P_{isolated}$).

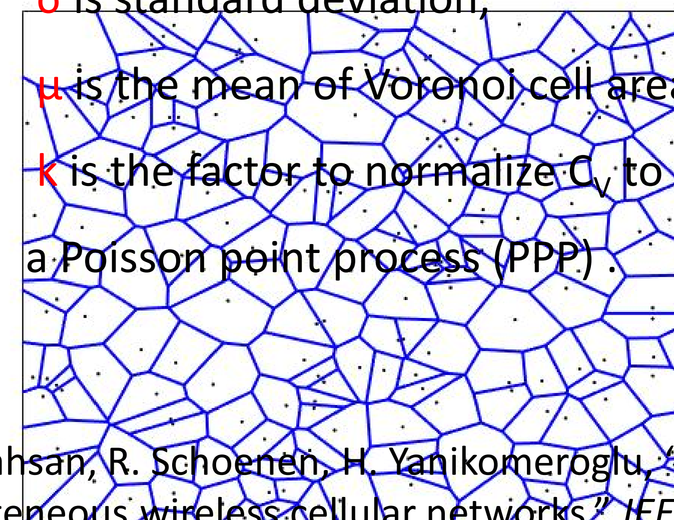
CoV-based Clustering Metrics

- Probabilistic Measure: Voronoi Tessellation areas
- Statistics: scaled CoV
- **Voronoi Tessellation:** Given a set of points (seed), the plane is partitioned … a seed, and this cell consists of all … than any others.

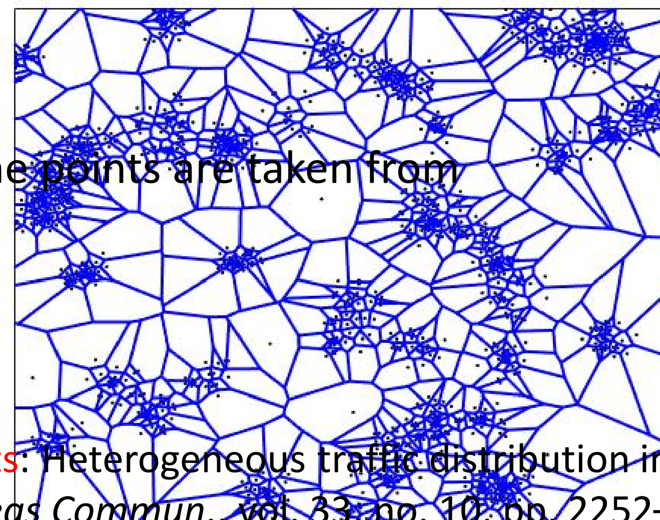
$$C_V = \frac{1}{k} \cdot \frac{\sigma}{\mu}, \qquad k \approx 0.529,$$

  – σ is standard deviation,
  – μ is the mean of Voronoi cell areas,
  – k is the factor to normalize C_V to 1 when the points are taken from a Poisson point process (PPP) .

M. Mirahsan, R. Schoenen, H. Yanikomeroglu, "HetHetNets: Heterogeneous traffic distribution in heterogeneous wireless cellular networks," *IEEE J. Sel. Areas Commun., vol. 33, no. 10*, pp. 2252–2265, Oct. 2015.



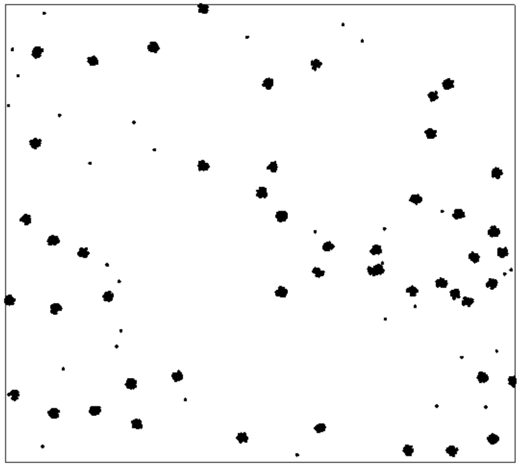
Voronoi of PPP traffic



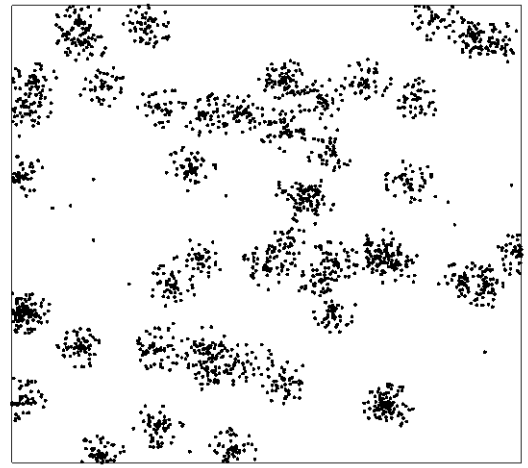
Voronoi of clustered traffic

Different Spatial Traffic and their C_V

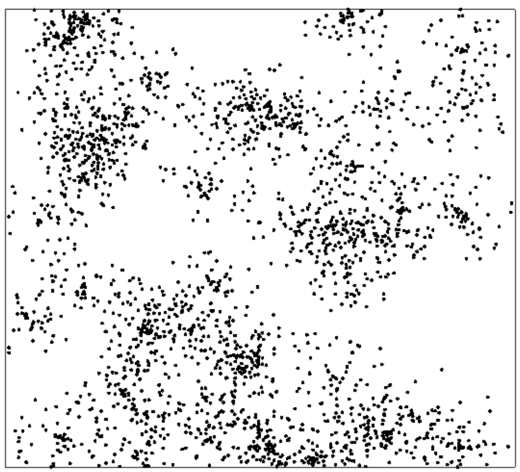
2000 points



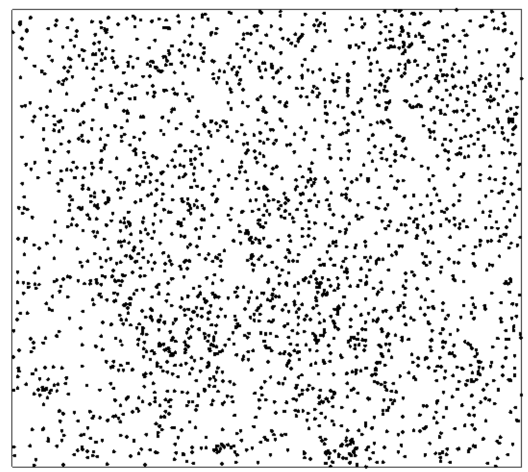
R=10, C_V=8.2937



R=50, C_V=4.9086



R=100, C_V=3.4129

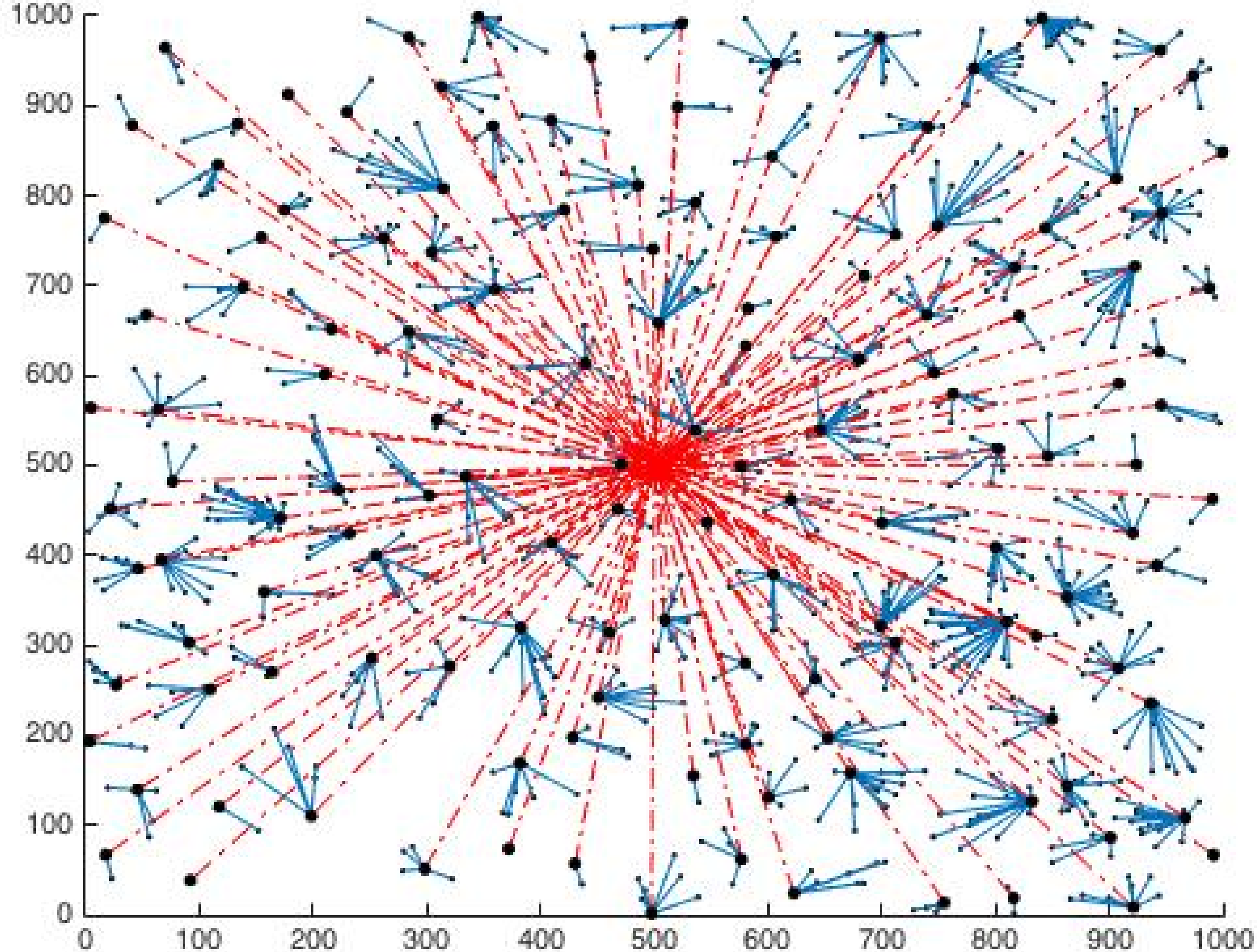


Homogeneous, C_V=1.1768

$C_V=1$: Poisson Point Process. $C_V>1$: super-Poisson/cluster. $0<C_V<1$: sub-Poisson.
As traffic becomes more heterogeneous/clustered, C_V becomes higher.

Results of Hierarchical Clustering Algorithm on Different Amounts of Clustering

2000 points



CoV=1.2936

Simulation Results

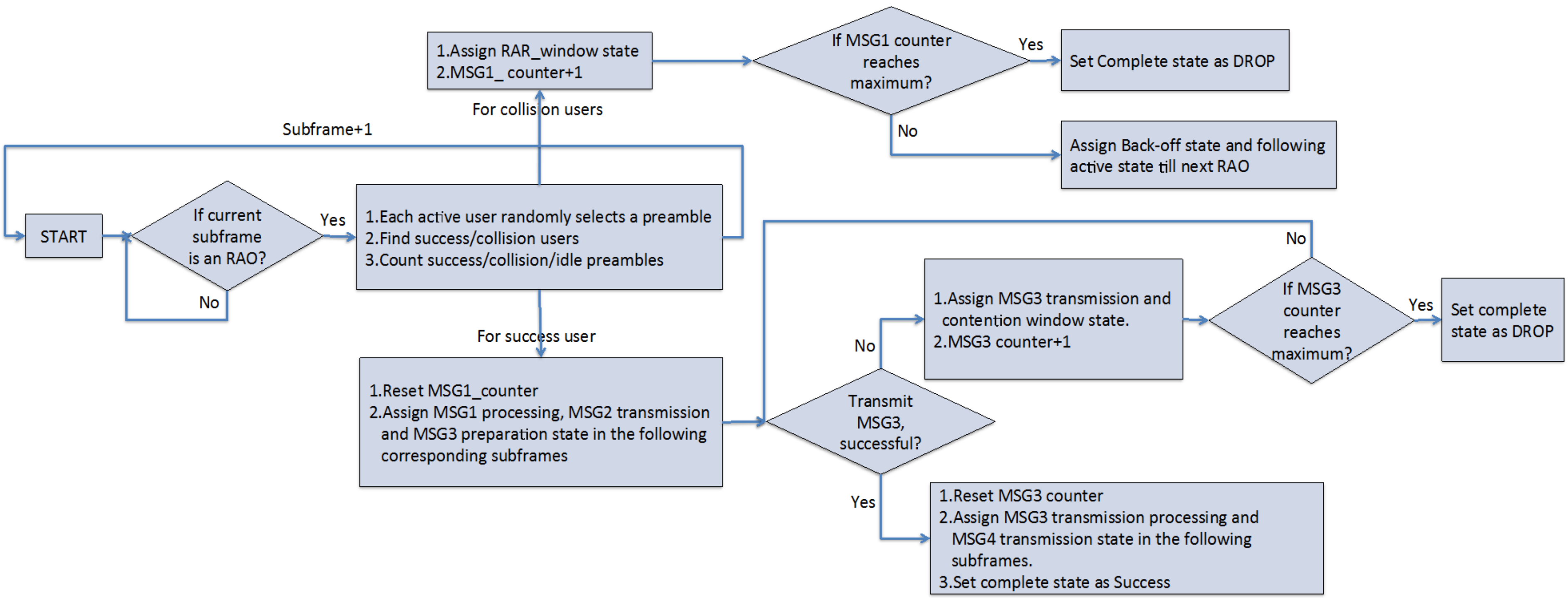
Simulation Parameters

Symbol	Parameter	Value
B	Cell bandwidth	5 MHz
-	PRACH configuration index	6
$N_{preamble}$	Total number of preambles	54
$Max_{preamble}$	Maximum number of preamble transmissions	10
-	Number of CCEs allocated for PDCCH	16
-	Number of CCEs per PDCCH	4
T_{RAR}	Ra-Response WindowSize	5 ms
T_{CR}	Mac-contentionResolutionTimer	48 ms
BI	BackoffTimer	20 ms
$P_{MSG3coll}$	Probability of successful delivery for both MSG3 & MSG4 (non-adaptive HARQ)	90%
$N_{MSG3max}$	Maximum number of MSG3 transmissions	5
-	Number of MTC devices	5k, 10k, 30k
-	Number of available subframes over the distribution period	10k, 60k
-	Period of PRACH opportunities	5 ms
T_{MSG1}	MSG1 transmission time	1 ms
T_{MSG2}	Preamble detection at eNodeB & MSG2 trans. time	3 ms
T_{MSG3}	Device processing time before sending MSG3	5 ms
$T_{TransMSG3}$	MSG3 transmission time	1 ms
T_{MSG4}	Time of processing MSG3 & sending MSG4	5 ms
T_{Tx}	Time of packet transmission in slotted ALOHA	1 ms
T_{RESP}	Response window size in slotted ALOHA	5 ms
T_{Rx}	Time of packet processing & acknowledgement transmission time	3 ms
P_{idle}	Power consumption in idle state	0.025 mW [28]
P_{Rx1}	Power consumption of processing and Rx in RACH	50 mW [28]
P_{Tx1}	Power consumption of Tx in RACH	50 mW [28]
P_{Rx2}	Power consumption of processing and Rx in slotted ALOHA	25 mW [29]
P_{Tx2}	Power consumption of Tx in slotted ALOHA	25 mW [29]

3GPP
LTE Network

F. Alsewaidi, D. Kaleshi, A. Doufexi, “Analysis of Radio Access Network Performance for M2M Communications in LTE-A at 800 MHz,” in *IEEE WCNC 2014 IoT Commun. & Techn. Workshop*.

Reference Random Access Procedure

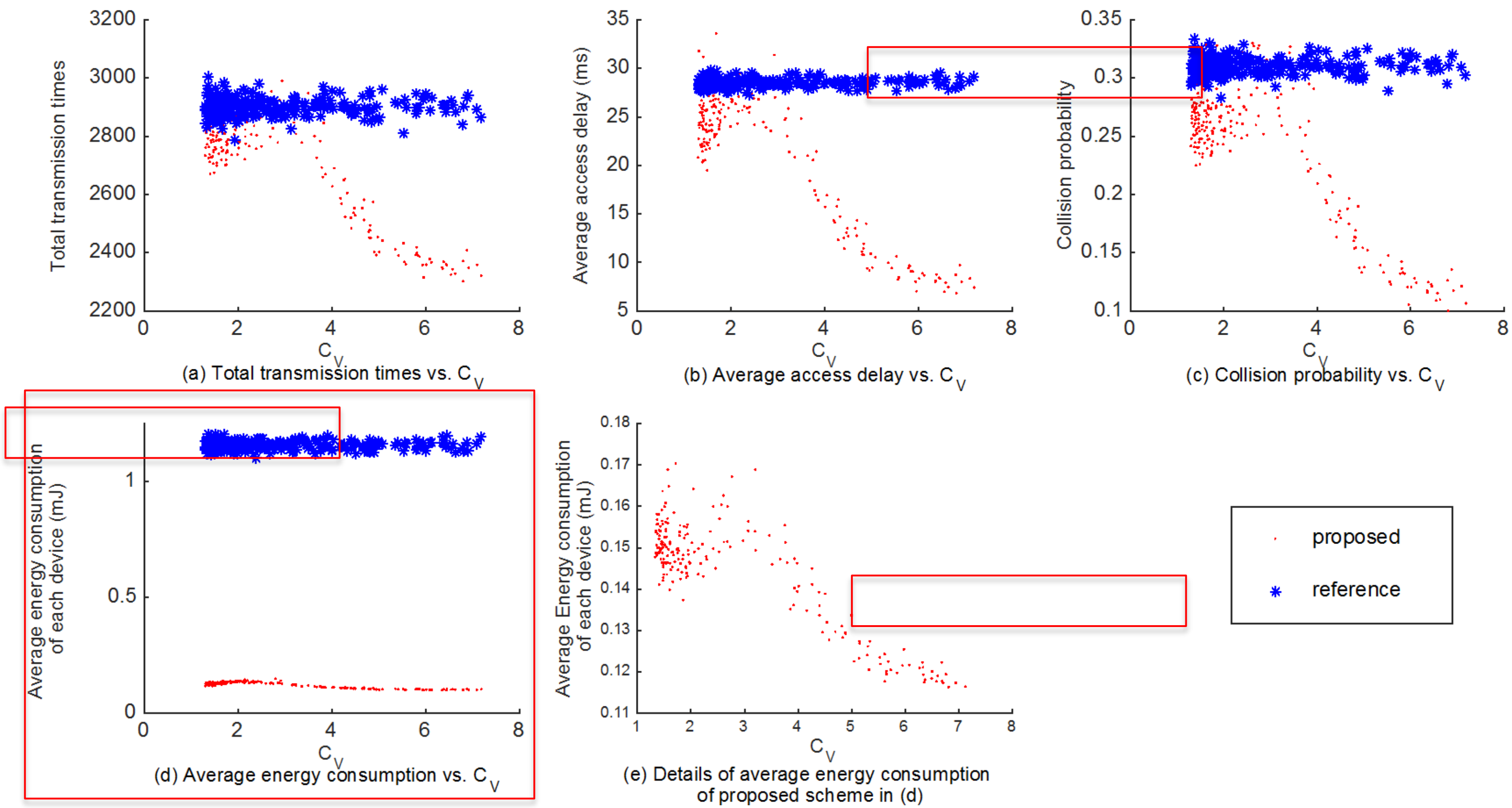


3GPP-Compliant LTE Random Access Simulator

Performances Measures	Number of MTC devices			
	5k	10k	30k	Result Origin
Collision Prob. (%)	0.01	0.03	0.22	3GPP
	0.01	0.03	0.23	Simulation
Success Prob. (%)	1.09	2.18	6.49	Simulation
Idle Prob. (%)	98.90	97.79	0.93	Simulation
Access Success Prob. (%)	100	100	100	3GPP
	100	100	100	Simulation
Avg. Access Delay (ms)	25.60	26.05	27.35	3GPP
	28.23	28.58	29.63	Simulation
Avg. Preamble Trans (%)	1.43	1.45	1.50	3GPP
	1.43	1.45	1.50	Simulation

"RAN improvements for machine-type communications,"
3rd Generation Partnership Project (3GPP), TR 37.868, Sept. 2012.

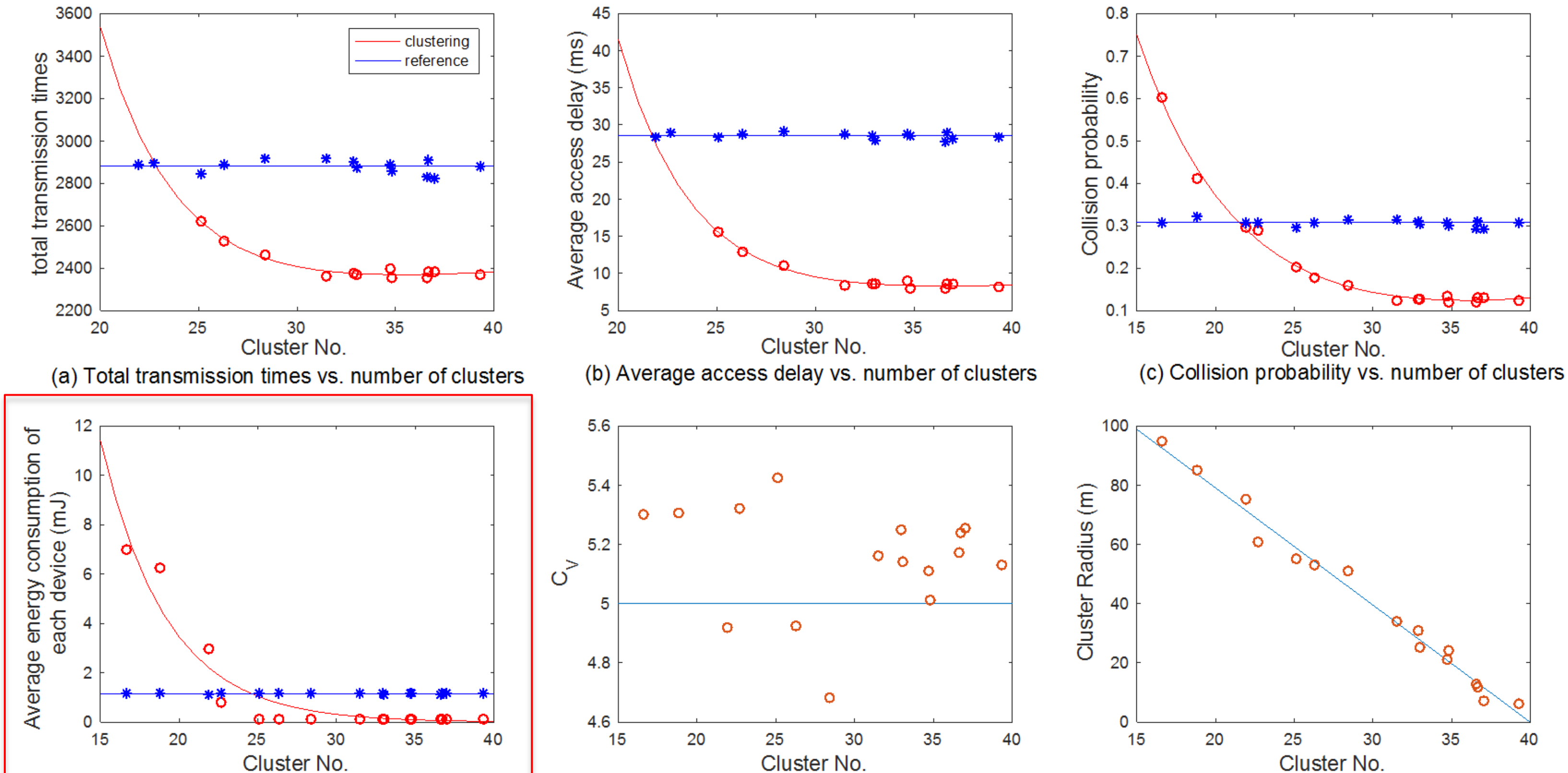
Performance vs. C_V



higher C_V → more clustered locations → less Interference → better performance

Why such a big difference in energy consumption Fig. (d)?

Performance vs. Cluster No. (C_v fixed)



(a) Total transmission times vs. number of clusters
(b) Average access delay vs. number of clusters
(c) Collision probability vs. number of clusters
(d) Average energy consumption vs. number of clusters
(e) C_V vs. number of clusters
(f) Tuning of cluster radius to maintain C_V=5

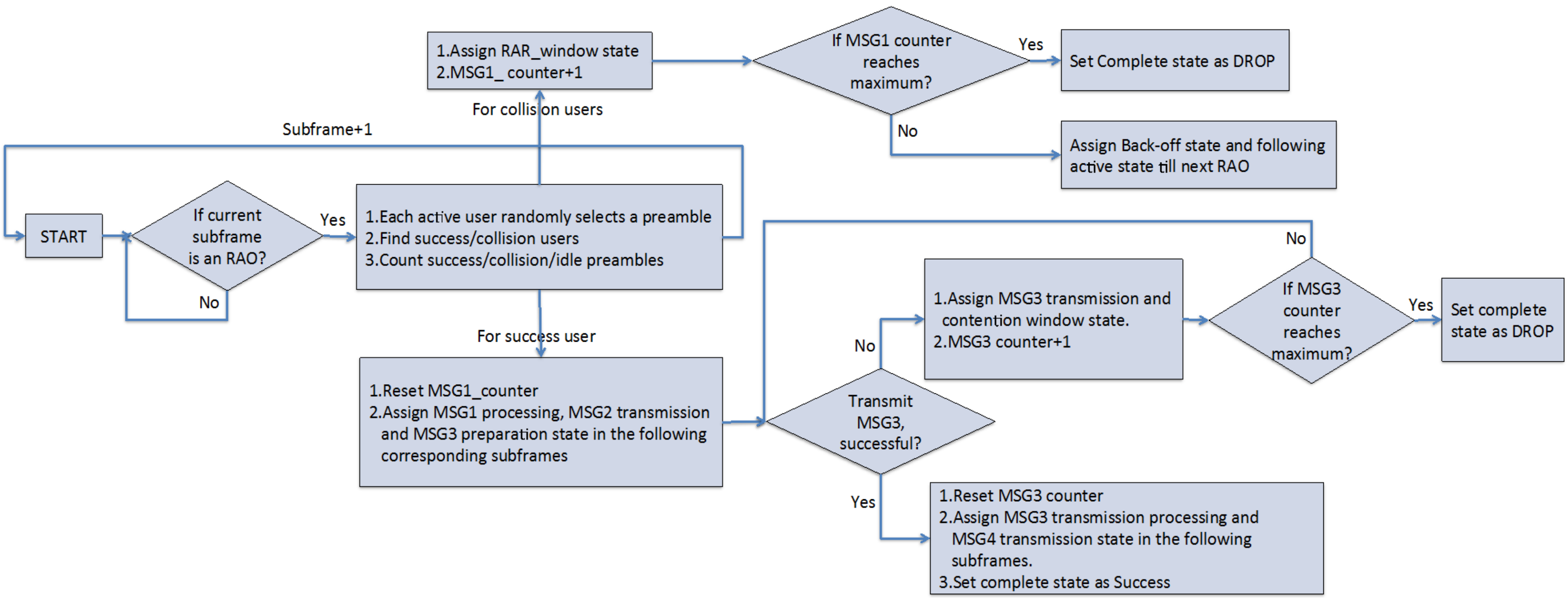
- The other inputs of location generator are N = 2000 and $P_{isolated}$ = 0.01.
- More clusters $\xrightarrow[(C_V \text{ fixed})]{}$ Smaller cluster radius → Less interference → Better performance
- The proposed scheme outperforms the reference scheme when 100 > M > 22, i.e., the number of machines per cluster < 90.

Conclusion

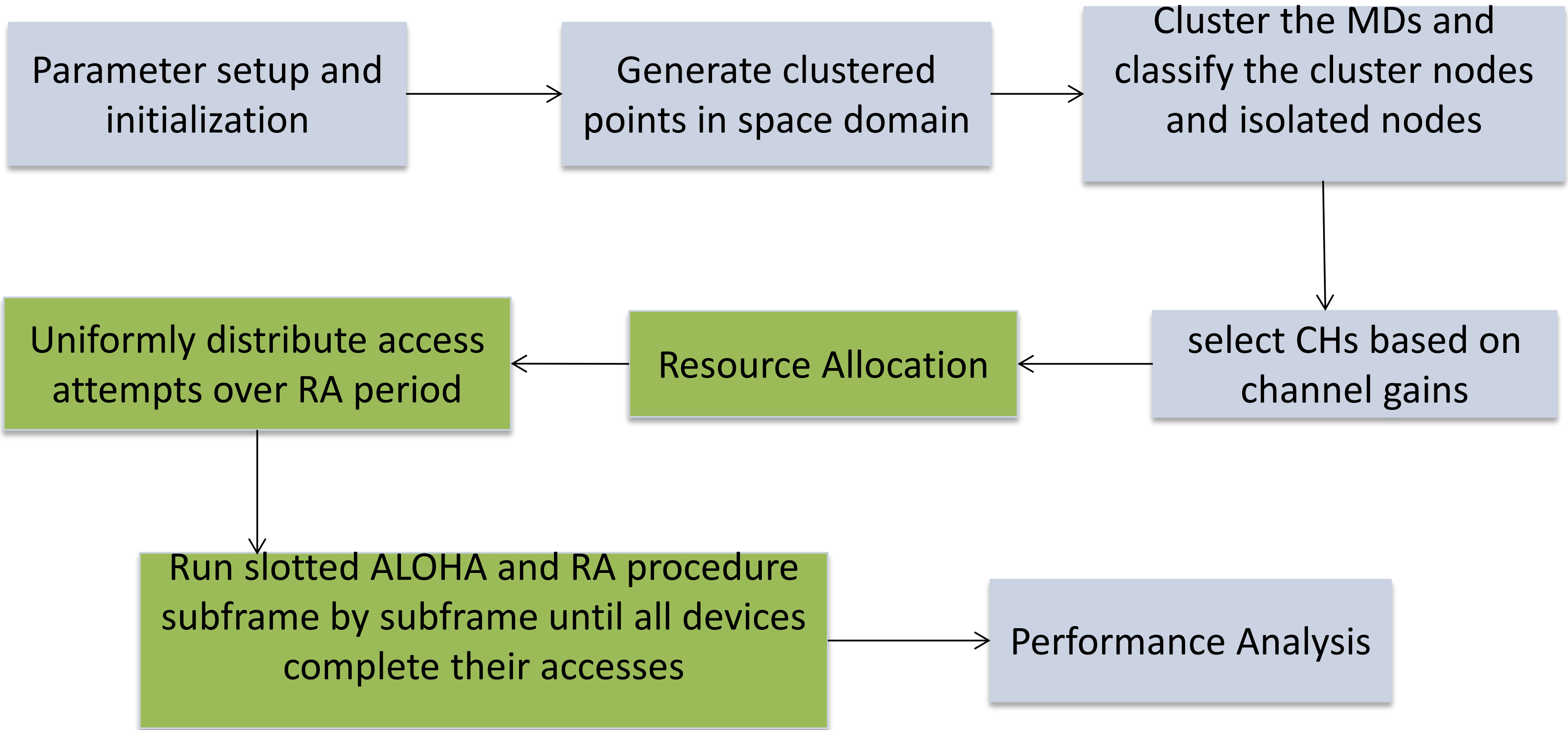
- Proposed a slotted ALOHA-based two-hop cluster random access method which significantly saves the energy for machines.
- Introduced a clustering geometry model for machine locations.
- Defined a clustering metric C_V.
- Conducted some literature review on different clustering algorithms.
- Examined the impact of different parameters ($C_{V,}$ device no., Cluster no.) on the system performance.

Thank you

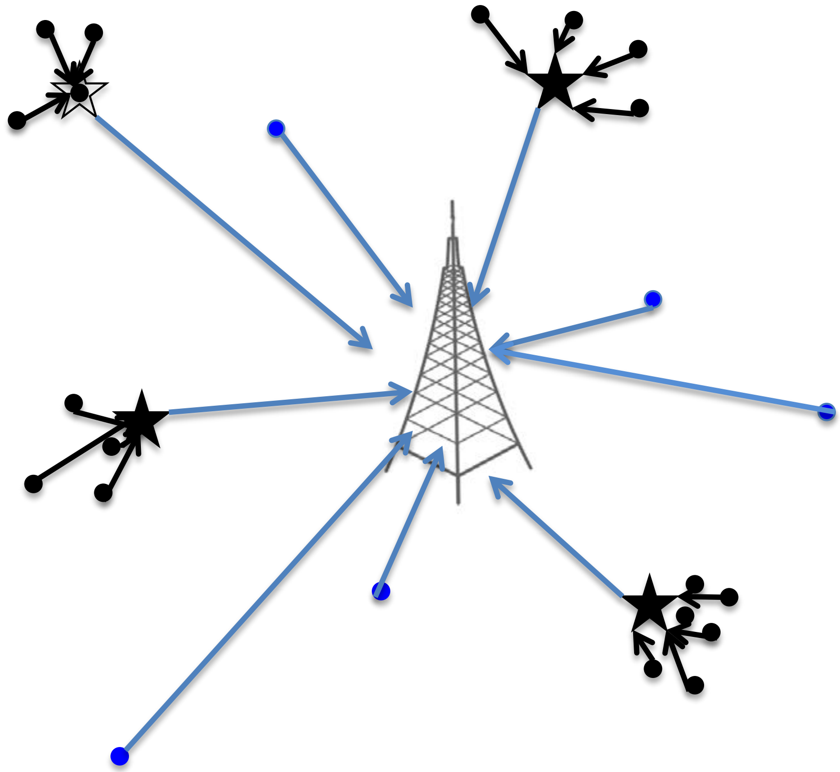
Reference Random Access Procedure



Simulation System Flowchart



System Model of Two-Hop Clustering Scheme



a. Generate a traffic pattern

b. Cluster all devices + select CHs

c. Two-hop Communication:

1. Intra cluster

   Cluster members upload packets to cluster head through slotted Aloha

1. Direct link between CH/ individual node with BS

   Once CH buffer reaches a certain level, it initiates random access to BS.

d. Resource allocation

- Resources for slotted Aloha are migrated from the original RACH to maintain the same amount of total resources and make a fair comparison.
- Full Resource Reuse for slotted aloha within each cluster.

e. Interference

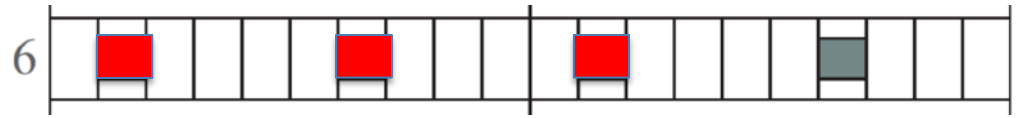
Simultaneous packet transmission in slotted aloha will cause interference. Only if SINR is beyond a certain level, transmission is successful.

f. Performance evaluation. Tuning different parameters to see the impact on performance.

Resource Allocation Scheme

1. Resource allocation between PRACH and slotted ALOHA

e.g. 3:1



1st hop   2nd hop   Note: More resources should be reserved for slotted ALOHA,
Only cluster head and individual ME contend in PRACH.

2. Intra-cluster communication (slotted ALOHA) reuse pattern

- Full reuse in each cluster.

→ **Interference**

- Any other simultaneous transmission from machines located at the same or different clusters will cause interference.
- If SINR>20dB, packet transmission is successful (slotted ALOHA).
- More clustered → less inter-cluster interference.

Channel Model

- ME transmit power 14dBm, Noise figure 9dB
- Pathloss exponent 4 (machine to machine)

Analysis of Energy Consumption wrt. Collision Probability

In slotted ALOHA

Transmission power: P_{Tx2} ; Receiving and processing power: P_{Rx2};

Transmission period: T_{Tx}; Response window: T_{RESP}; Receiving period: T_{Rx};

The probability that a CM needs to transmit N times:

$$P_{collision}^{N-1}(1 - P_{collision}).$$

The Energy consumed:

$$NT_{Tx}P_{Tx2} + [(N-1)T_{RESP} + T_{Rx}]P_{Rx2}.$$

The expected number of transmissions:

$$\sum_{N=1}^{\infty} N(P_{collision})^{N-1}(1 - P_{collision}) = \frac{1}{1 - P_{collision}}.$$

The expected energy consumption:

$$\frac{1}{1 - P_{collision}} T_{Tx}P_{Tx2} + \left[\left(\frac{1}{1 - P_{collision}} - 1\right)T_{RESP} + T_{Rx}\right]P_{Rx2}$$

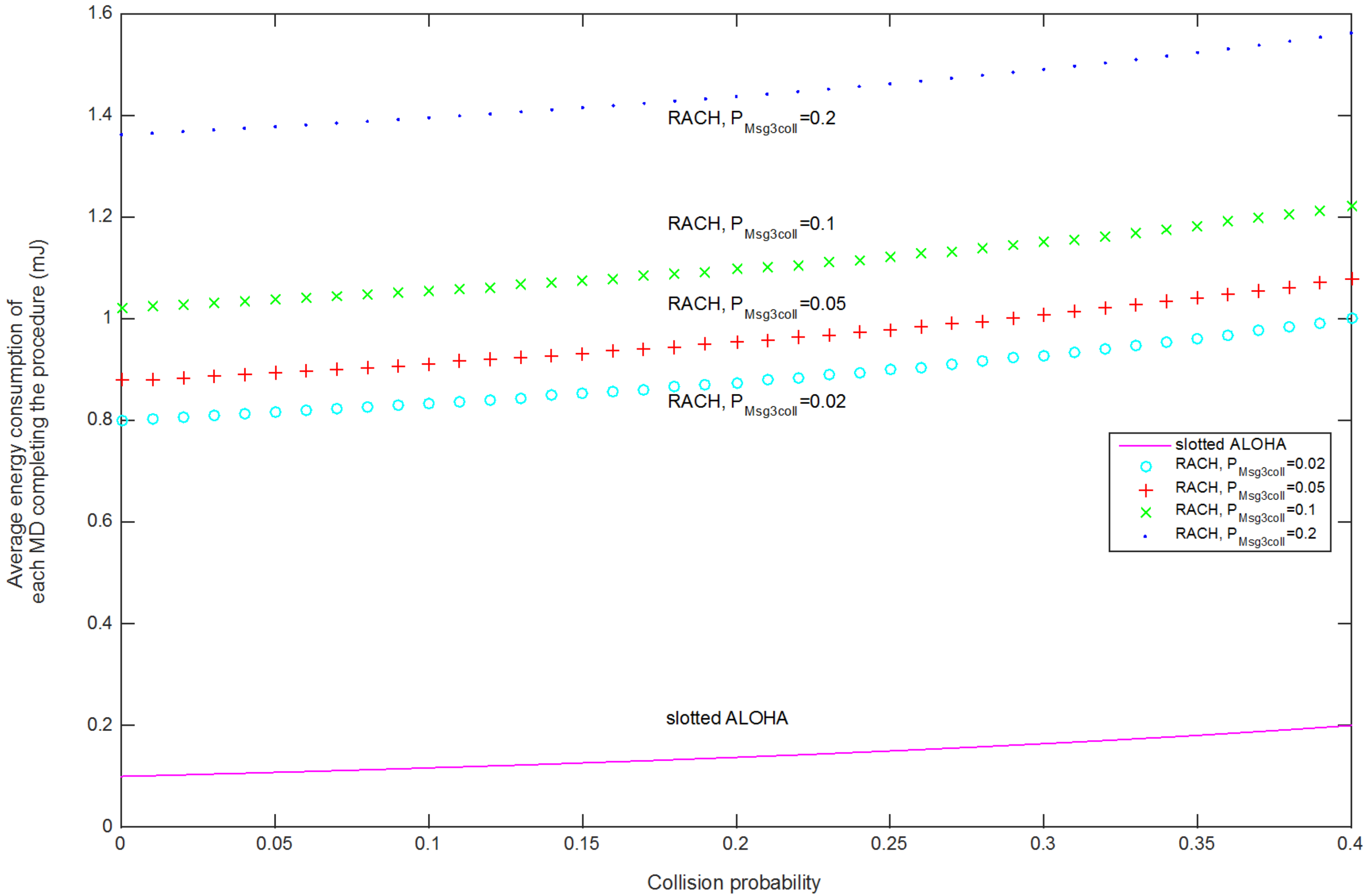
Analysis of Energy Consumption wrt. Collision Probability

In RACH

Similarly, the expected energy consumption:

$$\left(\frac{1}{1-P_{Msg1coll}}T_{MSG1}+\frac{1}{1-P_{Msg3coll}}T_{TransMSG3}\right)P_{Tx1}+$$
$$\left[\left(\frac{1}{1-P_{Msg1coll}}-1\right)T_{RAR}+T_{MSG2}+T_{MSG3}\right.$$
$$\left.+\left(\frac{1}{1-P_{Msg3coll}}-1\right)T_{CR}+T_{MSG4}\right]P_{Rx1}.$$

Analysis of Energy Consumption wrt. Collision Probability



Definition of Performance Metrics

Total transmission times

- Reference Scheme: the total number of preambles sent by all machines in RACH
- Proposed Scheme: the total transmission times of all cluster members in slotted aloha + the total number of preambles sent by CH and individual node in RACH

Average access delay

- Reference Scheme: from first access subframe to the access complete subframe
- Proposed Scheme
  - slotted aloha: from the first packet transmission subframe to its packet successfully uploading subframe
  - RACH: from first access subframe to the access complete subframe

Average

Energy Consumption

- Reference Scheme: energy dissipation in RACH
- Proposed Scheme: energy dissipation in slotted aloha+ RACH

Definition of Performance Metrics

Collision rate: $\dfrac{\text{Collision Transmission Times}}{\text{Total Transmission Times}}$

- Reference scheme: only in RACH
- Cluster Scheme: both RACH and Slotted Aloha

Some Assumptions in Simulation

For Slotted Aloha

- all packet transmission can be finished in one subframe.
- Use ACK to confirm successful transmission in slotted aloha
- the ACK response will be acknowledged immediately/in the current subframe.
- Packet can be decoded successfully only if Interference is under a certain level.
- For slotted aloha, backoff is done only across slotted aloha access slots
- Once uploading data, device state is complete with assumption his CH will get access successfully in future
- Buffer has no limit

For Other Parts

- distribute access uniformly over RACH period