Efficient Location Based Services for Groups of Mobile Users

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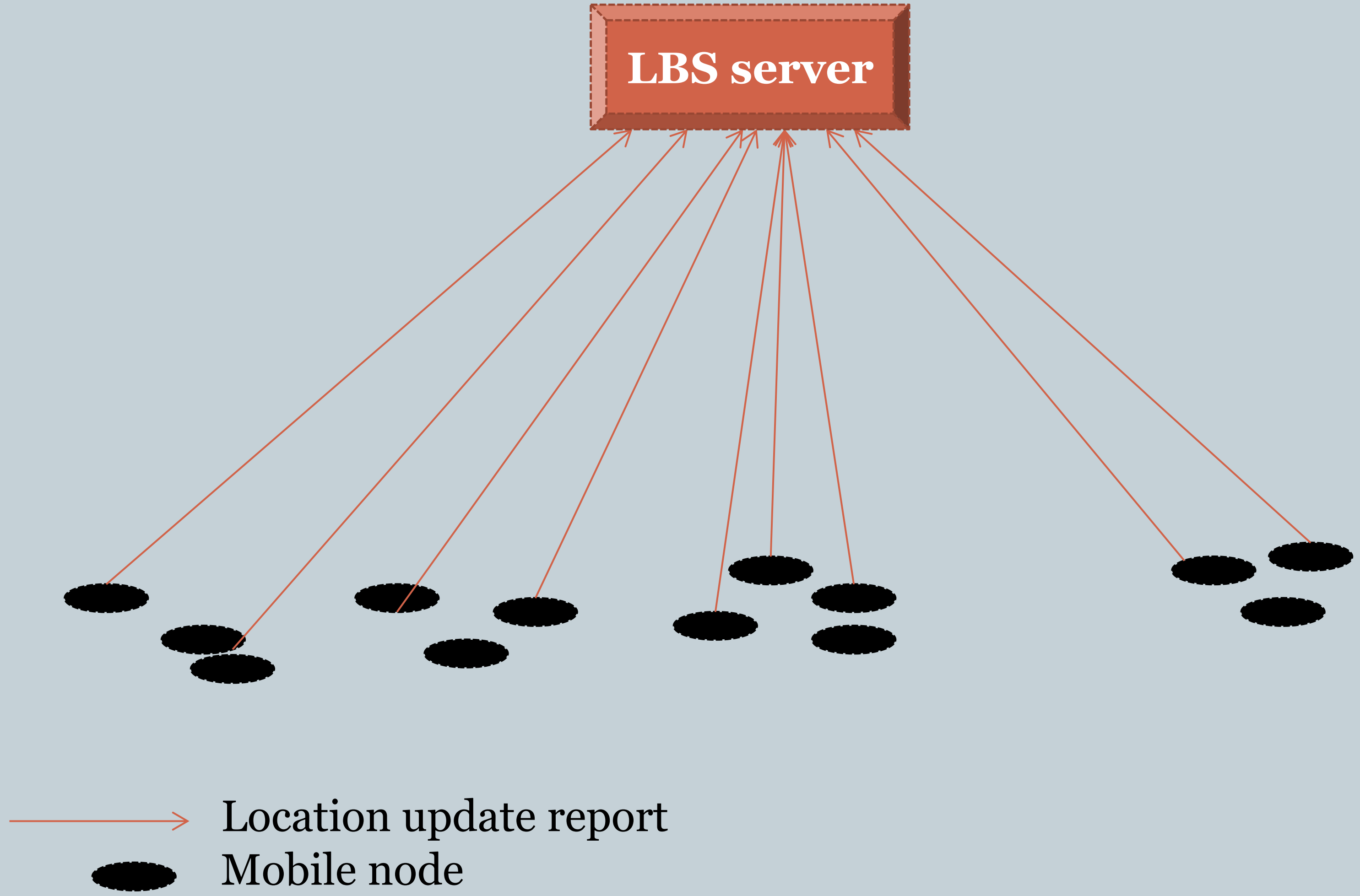
14th IEEE intl. conf. on mobile data management
Milan, 3-6 June 2013

Observation

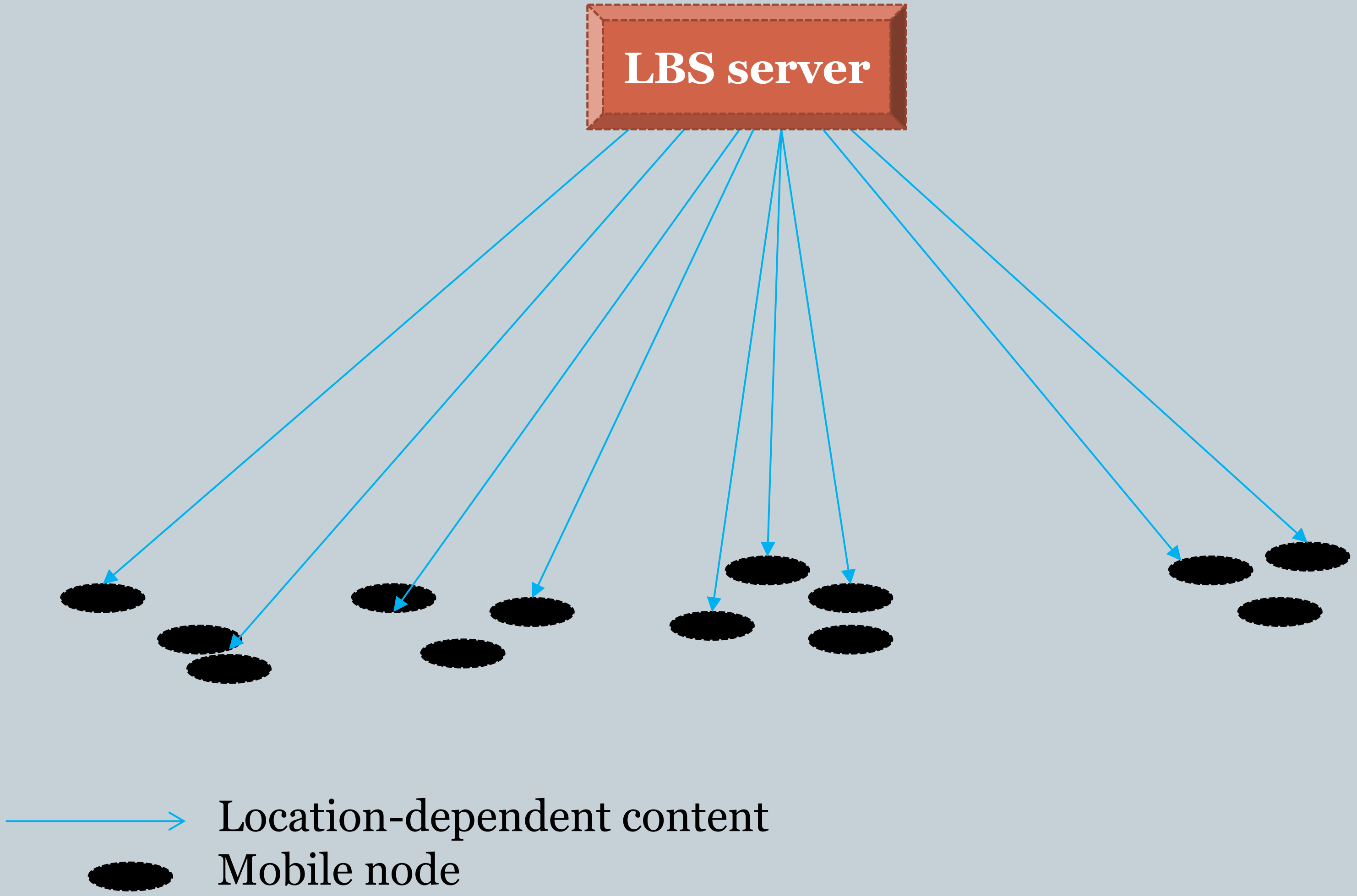
- Mobile users **send** location updates to LBS server (back-end system; BES)

- The BES **pushes content** (possibly, personalized) to a mobile user **if** she enters/crosses a **region**

Observation



Observation



Observation

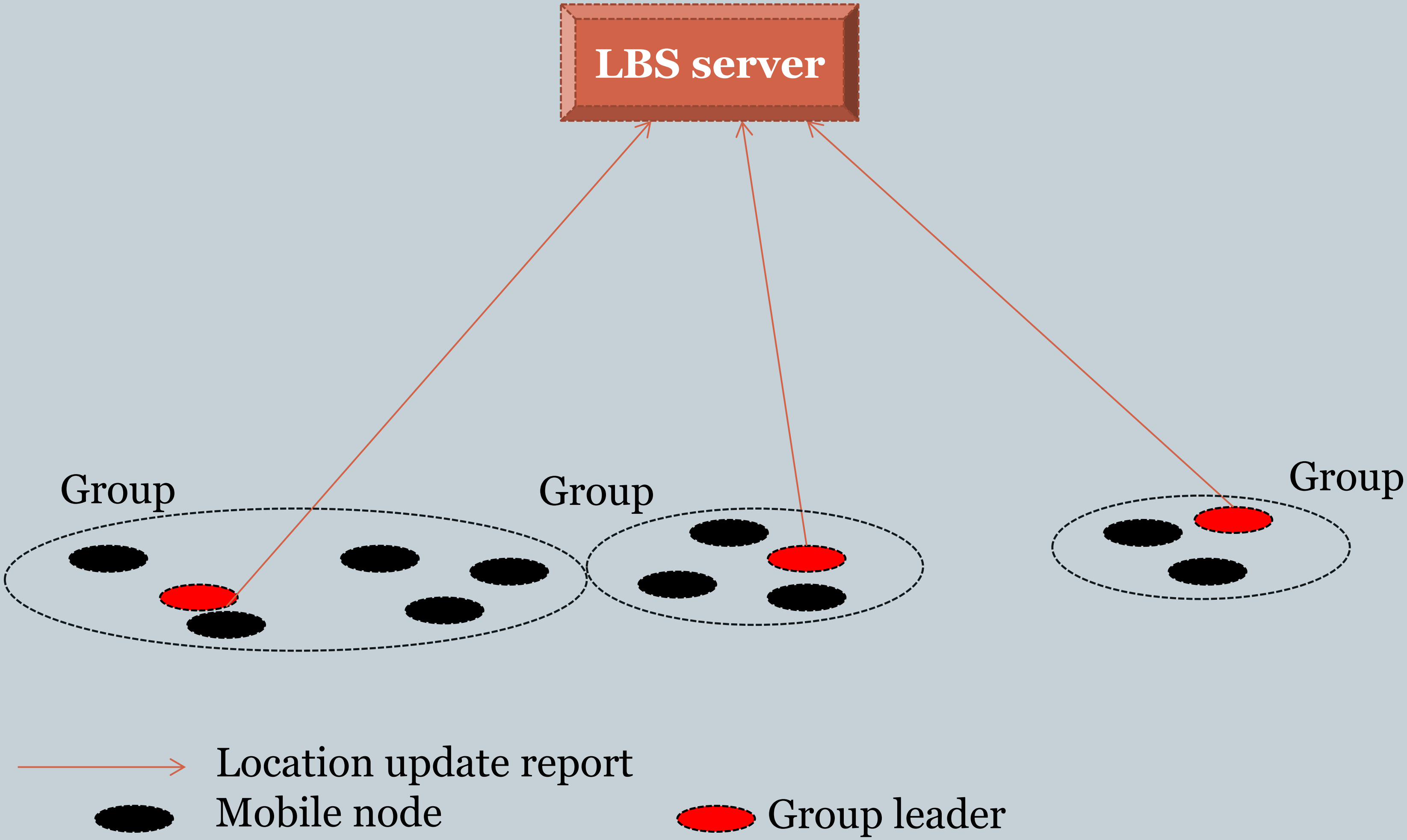
- As the **number** of mobile users increases, and
- As the users **continuously change** their position **then**
- The **communication overhead** for location reporting *and* location-based content delivery becomes quite significant

Group Identification

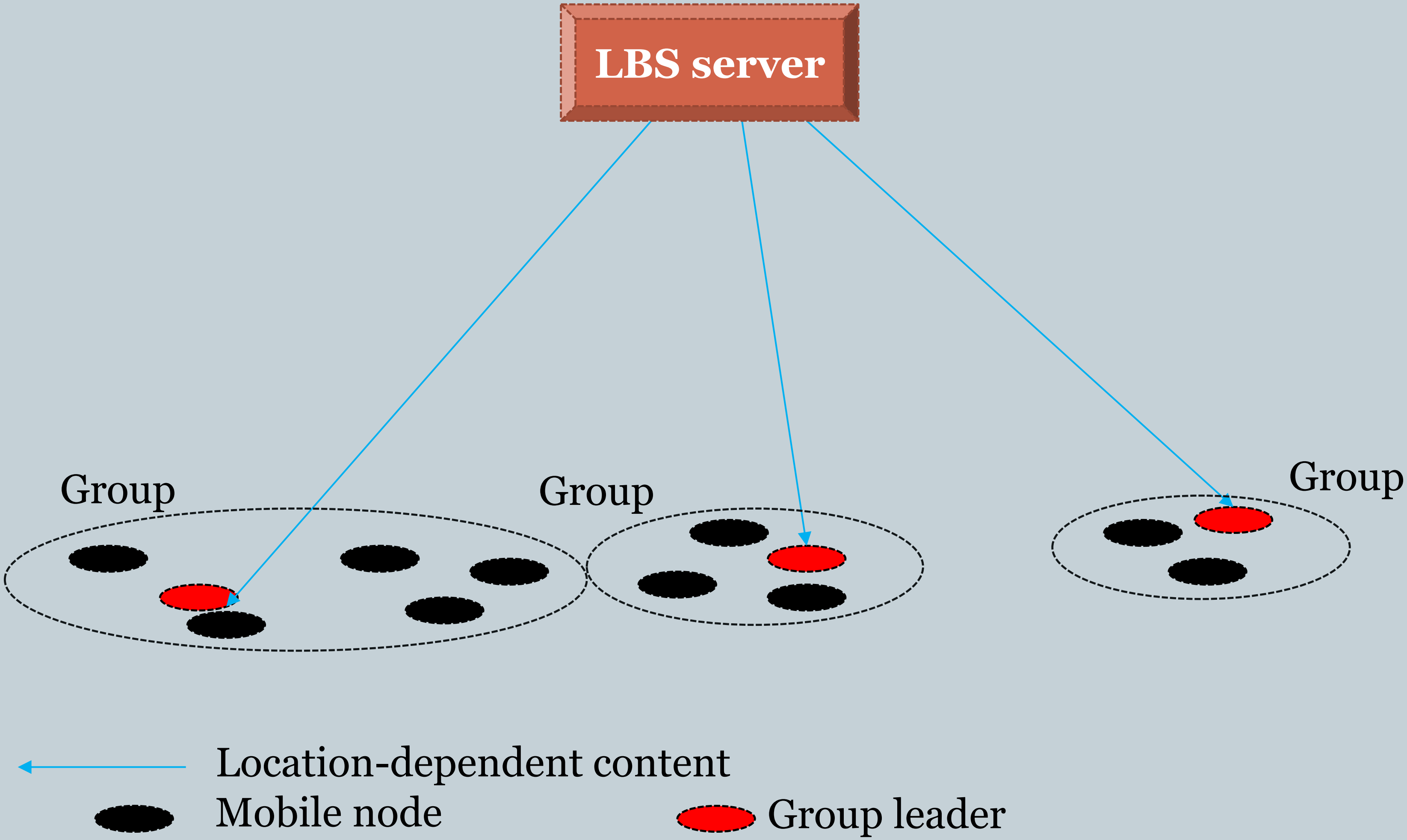
- Mobile users are not only **close to each other** but also likely to **move together** for a certain time horizon, thus, forming a **moving group**.

- A group has a unique **group leader** (GL).
- GL …is the **representative** of the group, i.e.,
  - **sends** location updates to BES
  - **receives** possible location-dependent content and **disseminates** it to its members

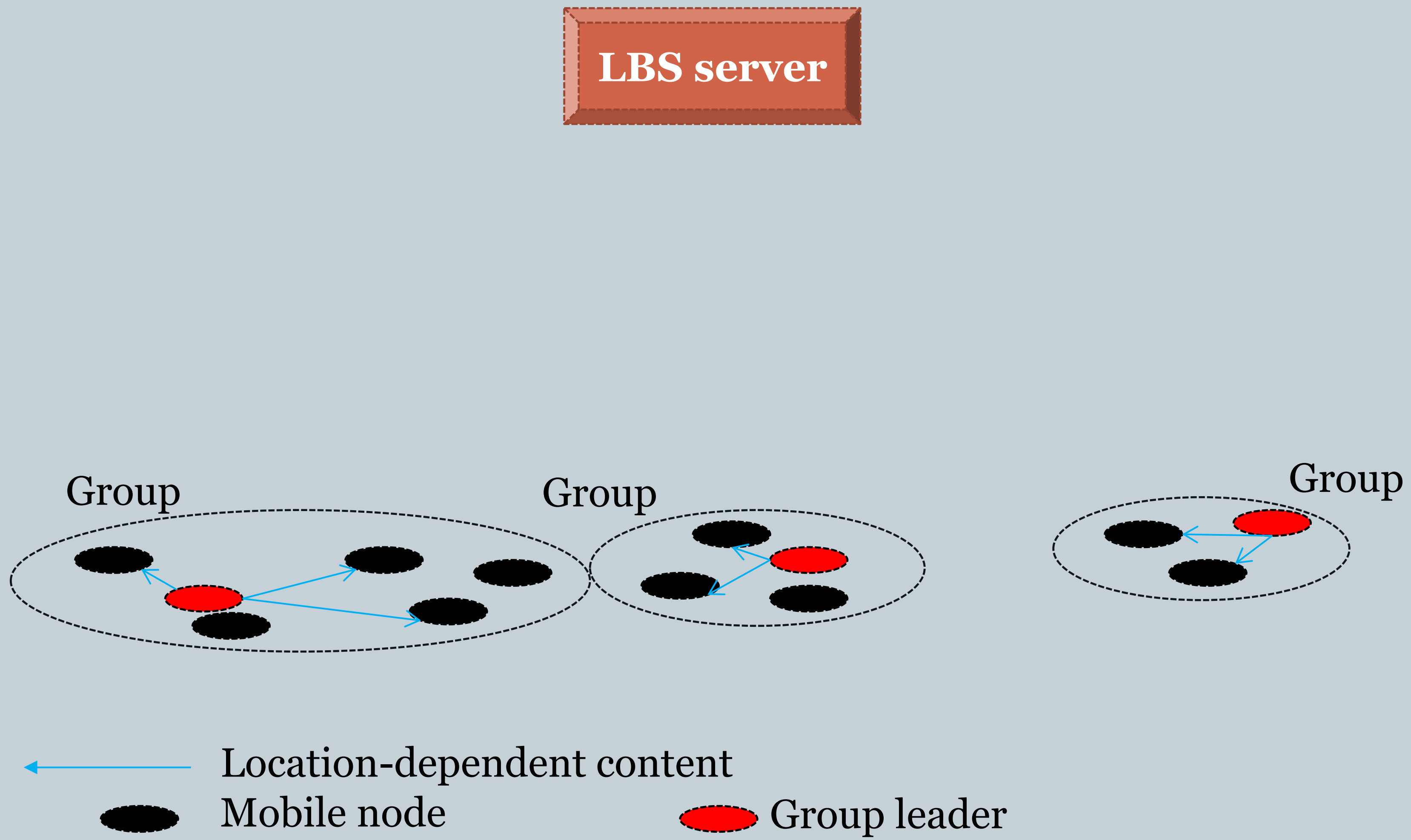
Moving Object Groups Monitoring



Moving Object Groups Monitoring



Moving Object Groups Monitoring



Problem

- **How** to *evaluate* that a formed group Q at time t, will remain the **same** group at time $t+k$, $k>1$

- …'same' group means:
  - **coherence**: group consists of the same mobile users as **initially** identified, and
  - **compactness**: all group members are **within** the communication range of the GL

during a *finite time horizon*

Some Definitions

Group Q is defined as: $Q = \langle l, V_l \rangle$

$$l = \arg\min_{u \in Q} \left\| \mathbf{p}_u - \mathbf{c}_Q \right\|$$ i.e., the GL of Q

$$\mathbf{c}_Q = \frac{1}{|Q|} \sum_{u \in Q} \mathbf{p}_u$$ i.e., the center point of Q

$$V_l = \left\{ u \mid \left\| \mathbf{p}_u - \mathbf{p}_l \right\| \leq R \right\}$$ i.e., the group members

Some Definitions

Group validity at (discrete) time t:

$$x_t = \left(\frac{1}{|Q|} \sum_{u \in Q} \left\| \mathbf{p}_u^t - \mathbf{c}_Q^t \right\| \right) \cdot I_{\left[\exists u \in V_l^t : \left\| \mathbf{p}_u^t - \mathbf{p}_l^t \right\| > R\right]} \left(V_l^t \right)$$

i.e., the average distance between members, *within the range of GL*, and group centroid

Group Validity and Validation System

- Consider a *clustering algorithm*, which is invoked periodically **every** N time instances and produces a set of groups $\boldsymbol{Q} = \{Q_1, Q_2, \ldots, Q_{|\boldsymbol{Q}|}\}$;

- Let $Q \in \boldsymbol{Q}$ be formed at t_0. Q is **valid** at $t > t_0$

$$\text{if } x_t \leq \theta$$

- The lower the x_t is, the more compact Q is at t

Group Validity and Validation System

Group Validation System (GVS)

[1] *monitors the behavior of Q in* $[t_o, k]$, i.e., *checks whether Q maintains its* ***initial*** *structure.*

[2] *considers Q as a* ***persistent*** *group in* $(k, t_o + N]$

At time t *in* $[t_o, k]$

(1) **each** member reports its location to BES; $f_t(|Q|)$

(2) GVS **evaluates** the group validity x_t; $g_t(|Q|)$

(3) Total **cost** c_t up to t is $c_t = \sum_{l=t_0}^{t} \left(f_l(|Q|) + g_l(|Q|) \right)$

Group Validity and Validation System

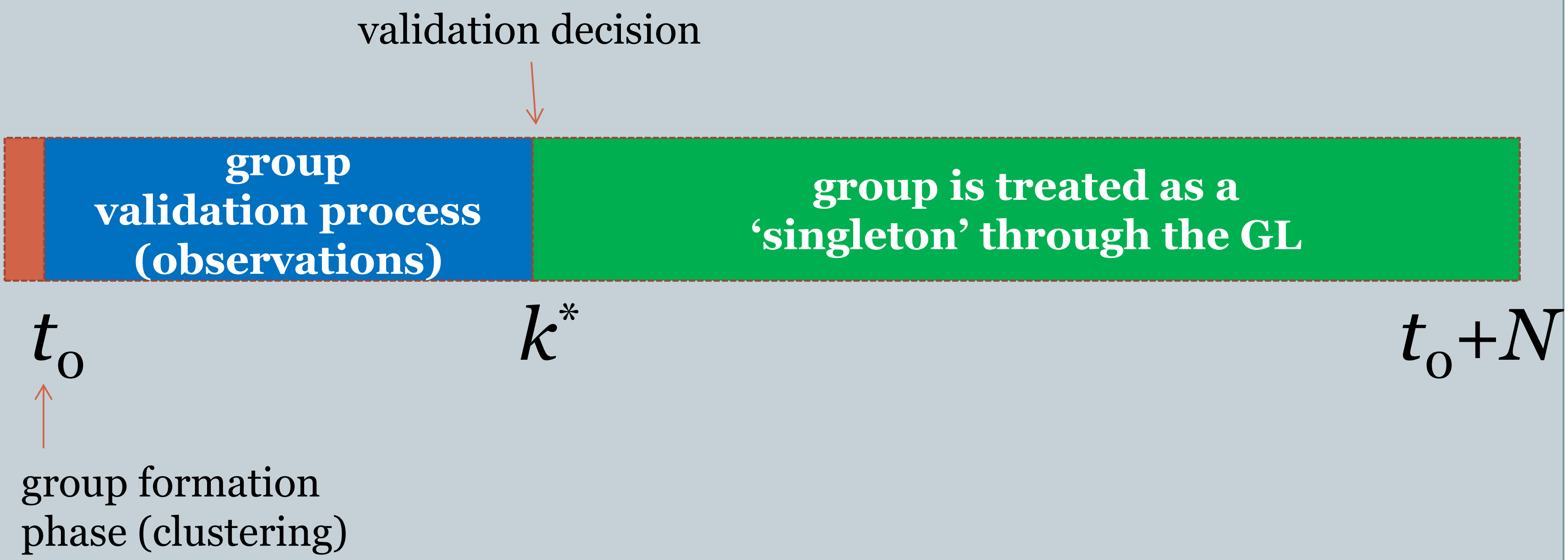
If GVS *validates* Q at k **then** for t in $(k, t_0 + N]$

(1) BES communicates **only** with GL;

(2) **only** the GL **reports** its location to BES;

(3) (possible) content is delivered to the members **through** the GL.

Formation, Validation & Persistence Phase



Group Validity and Validation System

The problem is to find (an optimal) time k^*, $1 < k \leq N$:

$$\inf_{1<k\leq N} E[X_k + c_k] = \inf_{1<k\leq N} E[X_k + kc]$$

Optimal Stopping Theory

- Choose the **best** time instance to take a decision of performing a certain action.
- **Observe** the current state of a system and decide whether to:
  - **continue** the process or
  - **stop** the process, and incur a certain **cost**.

- …the *odds* algorithm, the *secretary* problem, the *parking* problem, the *asset-selling* problem, etc.

Application to Group Validity Process

- Adoption of Optimal Stopping Theory for evaluating an criterion for k^*.
- The more **validity** values the GVS *observes*, the more *certain* is on concluding on a 'group persistence'

- The GVS **observes** X_t at each t. The **decision** is:
  - **stop** observing X_t and classify Q as *persistent*
  - **continue** observing X_{t+1} with *additional* **cost** C

- 'Finite' Horizon GVS (FVS), i.e., $1 < k \leq N$
- 'Infinite'-like Horizon GVS (IVS), i.e., $1 < k$

‘Finite’ Horizon GVS (FVS)

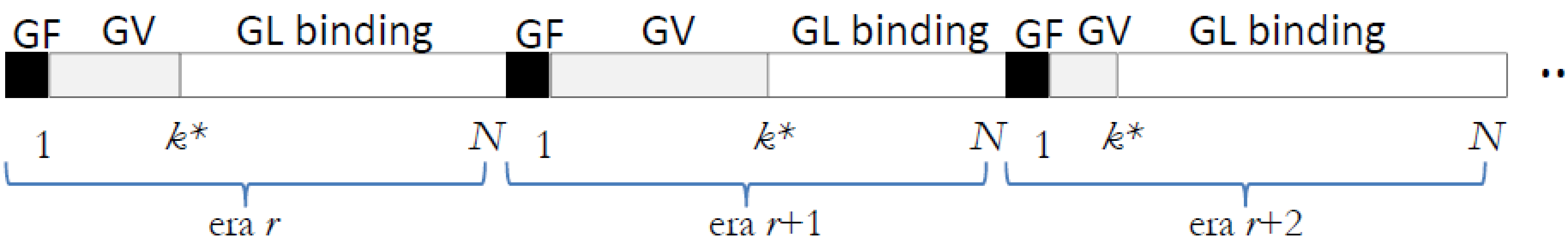
- FVS should *validate* Q **up to** N.
- The criterion is the sequence $(a_1, a_2, \ldots, a_N)$ such that FVS stops at t **iff** $x_t < a_t$

$$a_t = a_{t+1}\left(P_X\left(X \le x\right) - P_X\left(X \le a_{t+1}\right)\right) + \int_0^{a_{t+1}} x\,dP_X\left(x\right) + c$$

$$a_N = E[X] + c$$

- The {a ... n the ‘princ ... ction.

(FVS)



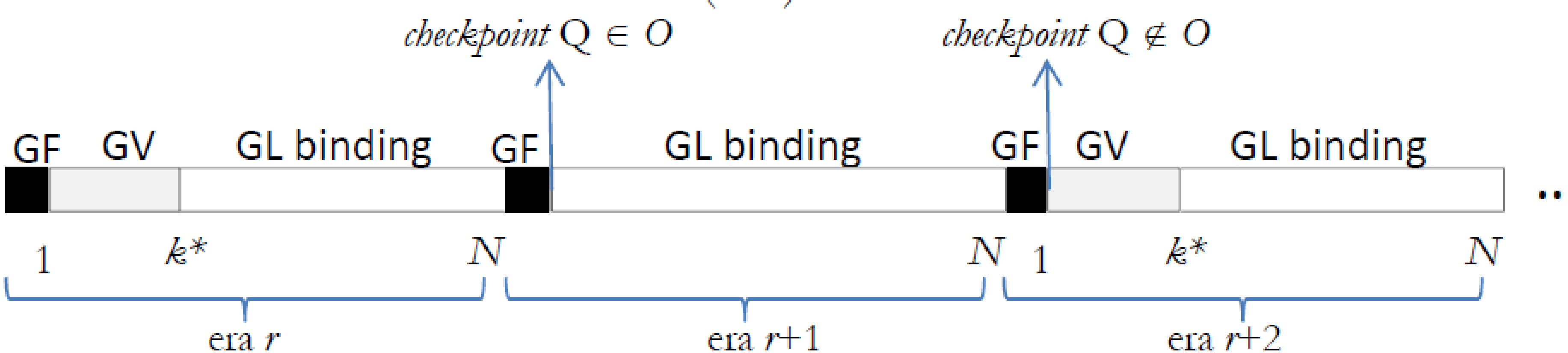
'Infinite'-like Horizon GVS (IVS)

- IVS *validates* Q independent of N.
- At certain **checkpoints**, it checks whether Q maintains its initial structure
- If Q i ... ting the v...

$$\int_0^{a^*} \left(a^* - x\right) dP_X\left(x\right) = c$$

- The criterion for optimal stopping is: stop at t **iff** $x_t < a^*$

(IVS)



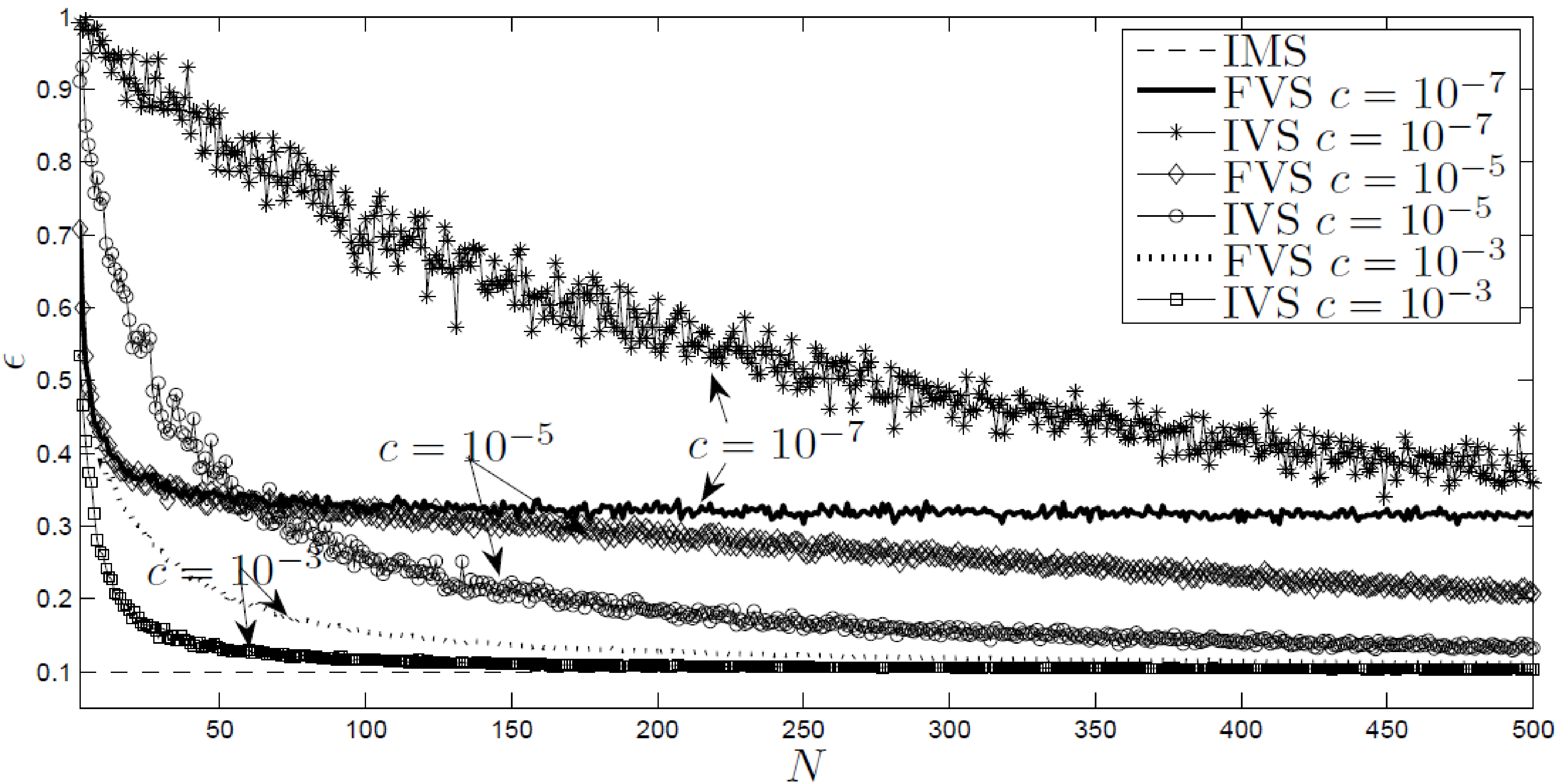
Performance Evaluation

Metric $\boldsymbol{\varepsilon}$:communication overhead during N (total number of messages) **w.r.t.** a continuous monitoring system.

- For a *continuous* monitoring system: $|Q|N$
- For FVS is: $|Q|k^* + (N - k^*)$
- For IVS is: $|Q|k^* + (Nm- k^*)$; m^{-1} = re-validation rate
- For IMS (immediate validation system) is: N

IMS: **periodically** performs re-clustering with freq. $1/N$

The load savings



Performance Evaluation

Required communication load:

$I_t = 1$, **if** Q is *valid* at t;

$I_t \in (1, |Q|]$, **otherwise**;

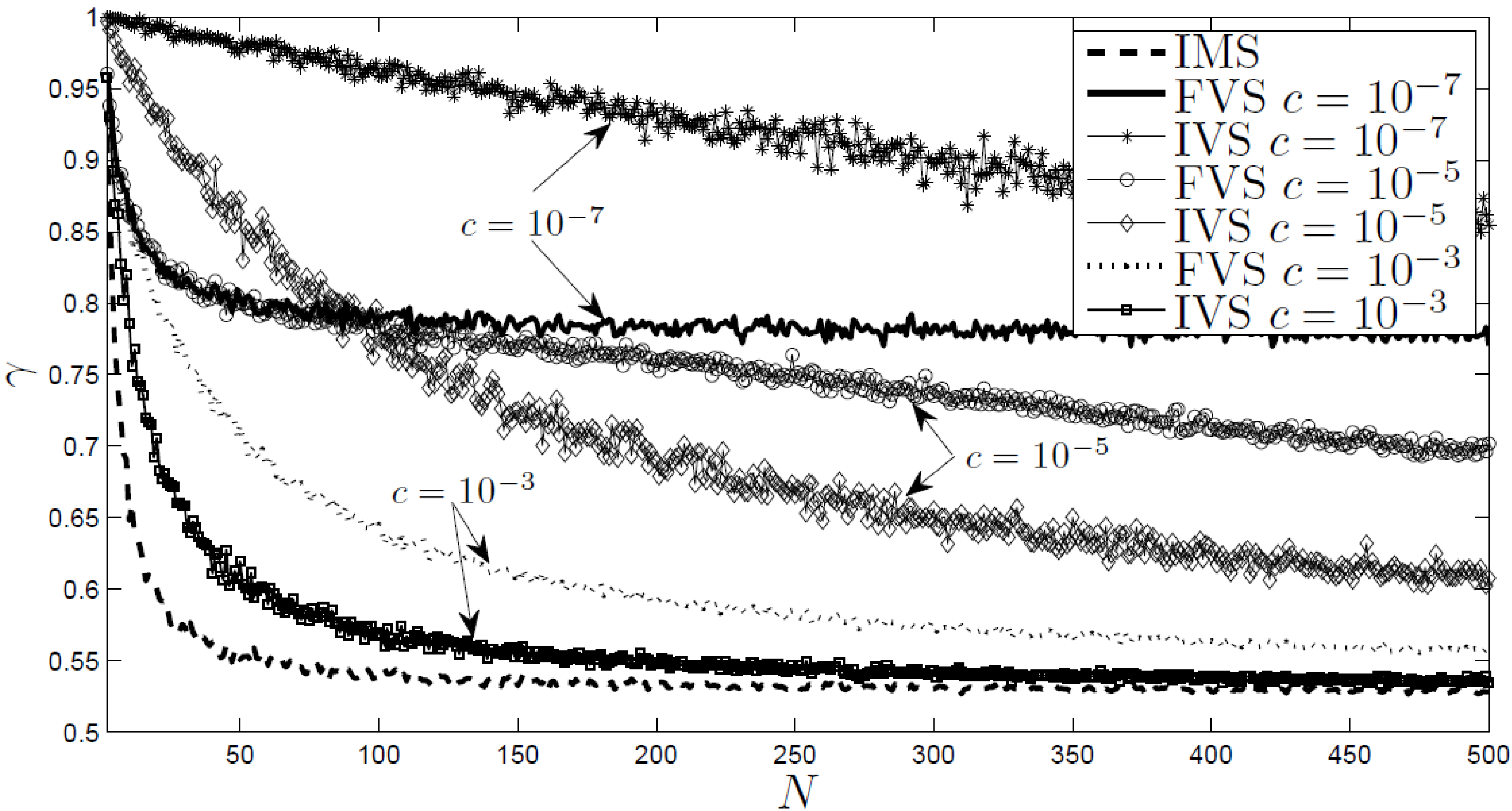
i.e., the case in which some members are *not* within the communication range of the GL.

Metric γ :efficiency is defined as:

$$\gamma = \frac{|Q|k^* + (N - k^*)}{|Q|k^* + \sum_{t=k^*}^{N} I_t} \qquad \gamma_{\max} \Leftrightarrow (N - k^*) = \sum_{t=k^*}^{N} I_t$$

Low γ indicates that the GVS **improperly** validated Q

The efficiency



Conclusions

There is **a trade-off** between:

- *validating* a group rapidly, thus, achieving low communication load (low ε) **and**
- *delaying* the validation decision for being certain on concluding on group persistence (high γ)

Thank you!