On Exploiting Diversity for Cluster Formation in Self-Healing MANETs

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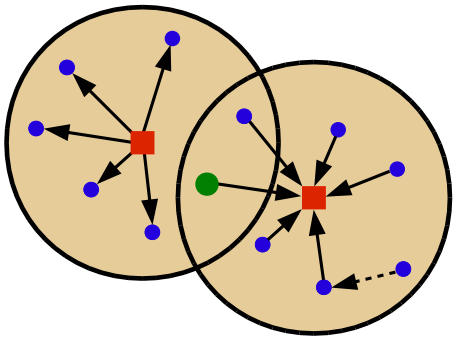
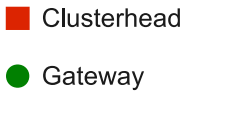
Introduction

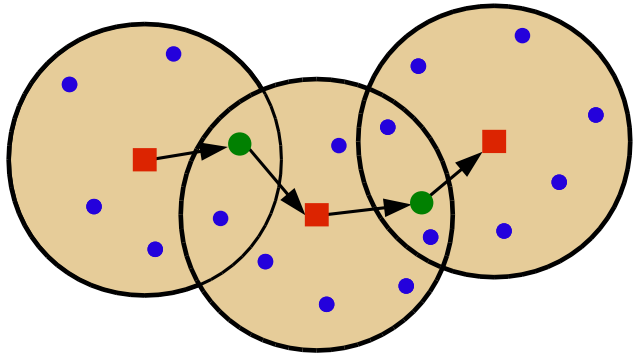
- Self-organizing ability is the key to self-healing networks, especially MANETs (mobile ad hoc wireless networks).
- The better the performance and robustness of a self-organizing mechanism, the better survivability of a network system.
- Clustering approach, a self-organizing mechanism, enables not only MANET scalability but also survivability.

Basics of Clustering

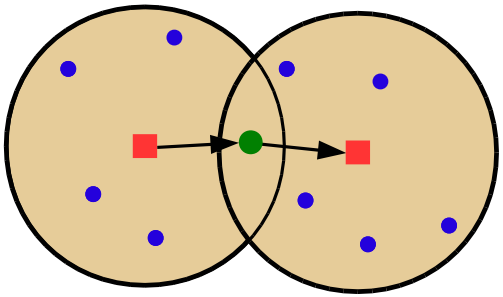


Intra-cluster communication

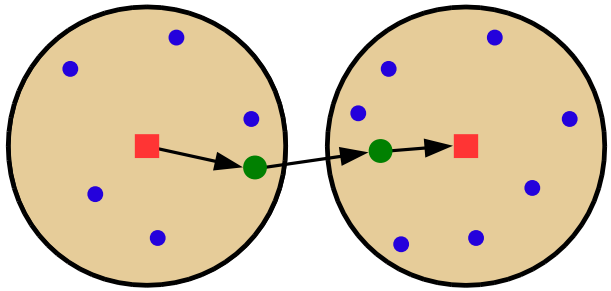




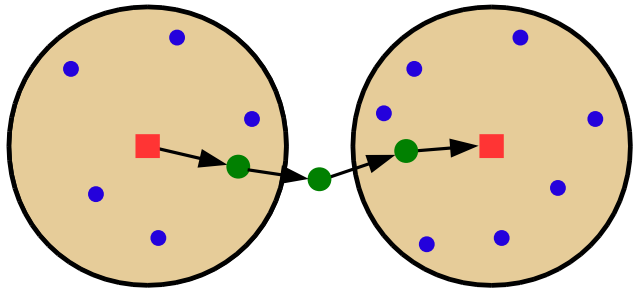
Inter-cluster communication



Direct gateway



Internal gateway



External gateway

Traditional Clustering Approaches: Merits

- Majority of them are decentralized algorithms.
- Cluster formation results in a communication hierarchy, enabling network scalability.

Traditional Clustering Approaches: Inadequacies

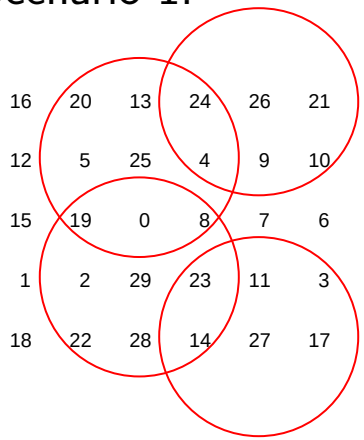
- Performance is heavily dependent upon network topology.
- Iterative execution is necessary for achieving satisfactory clustering coverage (the fraction of nodes that become organized through clustering).
- Cluster maintenance, which is often complicated and costly, are required to ensure persistent coverage.
- Hybrid/adaptive clustering methods apply alternate clustering policies conditionally (upon the detection of a poor coverage or CH-election conflict), limiting their performance gain.

Our Approach

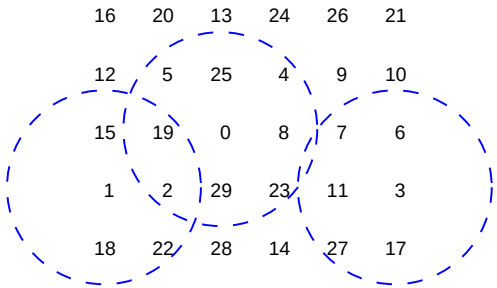
- Simultaneous application of diversified clustering policies.
- Complementary, superimposed cluster-layers resulting from diversified policies.
- A single-round protocol.
- Affordable partial redundancy pruning (no additional message exchanges required).

Superimposed Clustering: A MaxMin-Based Instance

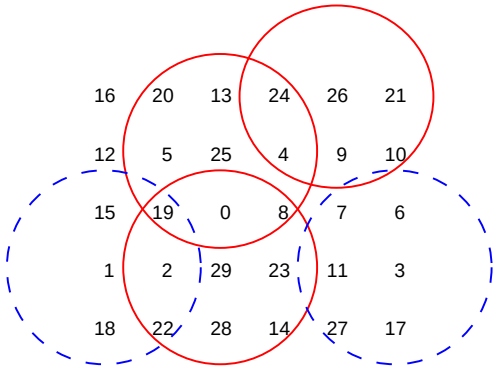
- Scenario 1:



(a) By Max-ID Policy

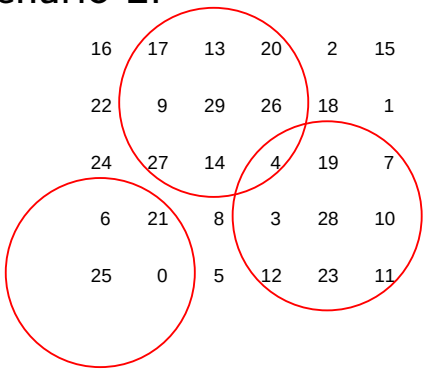


(b) By Min-ID Policy

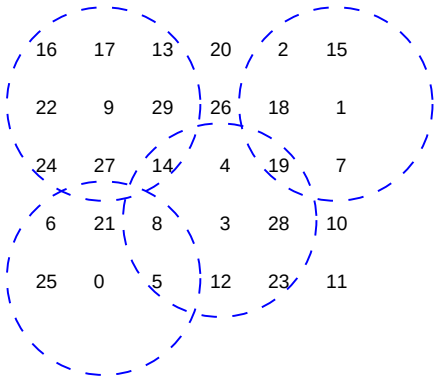


(c) By MaxMin-ID Policy

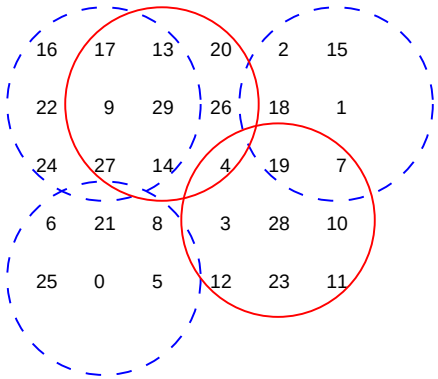
- Scenario 2:



(a) By Max-ID Policy



(b) By Min-ID Policy



(c) By MaxMin-ID Policy

SCP Algorithm

1: send(nID(v)); // ID diffusion
2: $N_1(v) \leftarrow$ receive(integerSet); // N_1 is a set of nIDs of 1-hop neighbors of v
3: send(nID(v),$N_1(v)$); // neighborhood info exchange
4: $N_2(v) \leftarrow$ receive(2-tupleSet); // N_2 is a set of $\langle nID, N_1 \rangle$
5: CHs(v) $\leftarrow$ identifyCH($N_2(v)$);
6: CHstatus(v) $\leftarrow$ redundancyChecking(nID(v), MAXorMIN(nID(v),$N_1(v)$), $N_1(v)$,$N_2(v)$);
7: send(nID(v), CHs(v), CHstatus(v), nil);
8: cRegistry(v) $\leftarrow$ receive(4-tupleSet);
9: CHstatus(v) $\leftarrow$ redundancyPruning(CHstatus(v), cRegistry(v));
10: identifyGW(cRegistry(v));

Principles of SCP

- Minimal message exchanges among the nodes: MaxMin-ID-based algorithm involves three message exchanges, the same as the Max-ID (or Min-ID) based algorithms.
- Emphasis on local computation: Neighborhood analysis, role identification, and redundancy checking/pruning are all performed locally at individual nodes.

  As message exchange is almost always the major drive of performance overhead and energy consumption in MANETs, the SCP approach can be justified by both its efficiency and affordability.

An Analytic Model

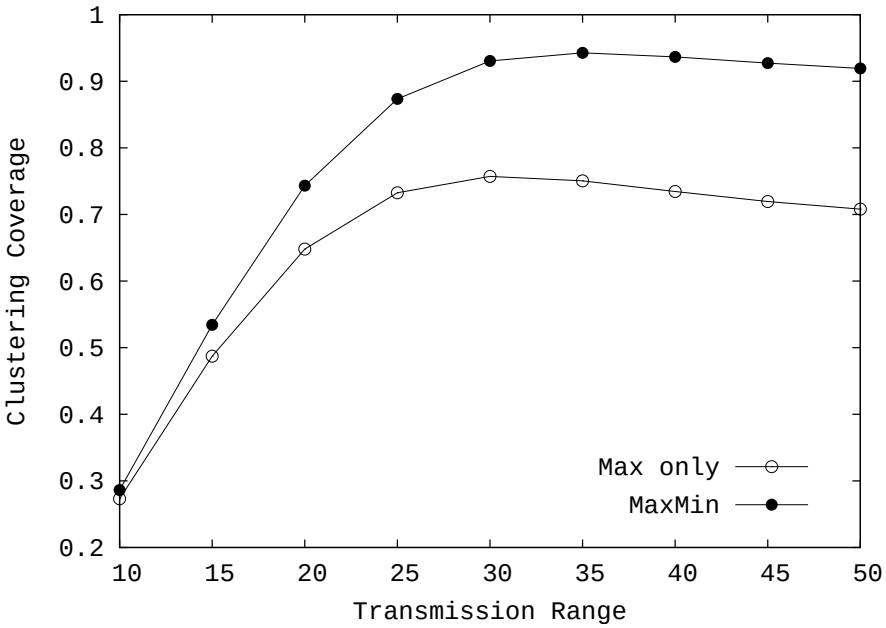
$$P(C_2) = \sum_{i=1}^{I_{max}} P(ID(v)=i) \sum_{n=1}^{I_{max}-1} P(\mid N_1(v) \mid = n) \; P(G_h(v)=1 \vee G_m(v)=1 \mid ID(v)=i, \mid N_1(v) \mid = n)$$

$$P(C_2) = \sum_{i=1}^{I_{max}} \frac{1}{I_{max}} \sum_{n=1}^{I_{max}-1} \binom{I_{max}-1}{n} \left(\frac{A_v}{A_t}\right)^n \left(1-\frac{A_v}{A_t}\right)^{(I_{max}-1)-n} \left(\frac{\binom{i-1}{n}}{\binom{I_{max}-1}{n}} + \frac{\binom{I_{max}-i}{n}}{\binom{I_{max}-1}{n}} + \right.$$

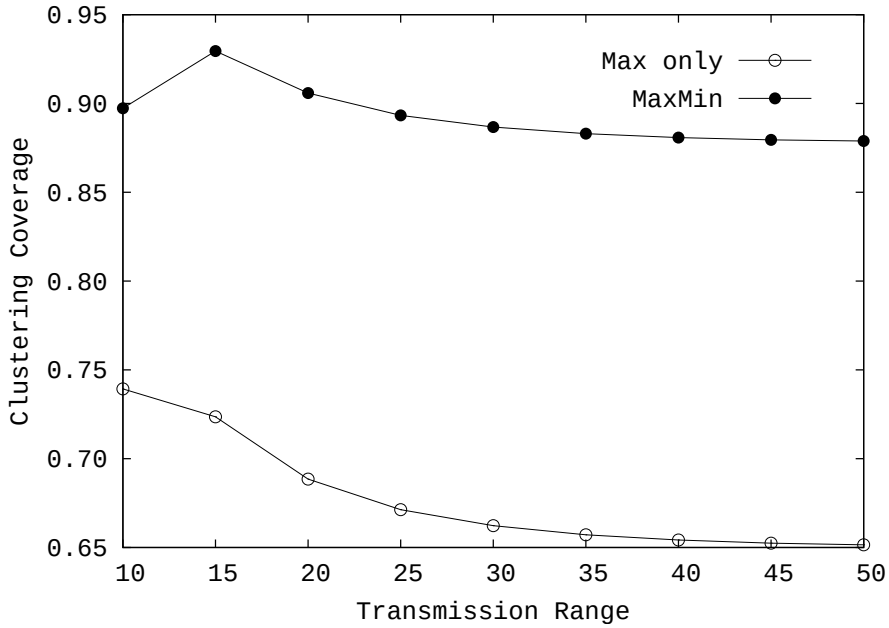
$$\left. \sum_{m=\max\{1,n-(i-1)\}}^{\min\{n-1,I_{max}-i\}} \frac{\binom{I_{max}-i}{m}\binom{i-1}{n-m}}{\binom{I_{max}-1}{n}} \left(1-\left(\sum_{j=i+1}^{I_{max}} \frac{1}{I_{max}-i}\left(1-\left(1-\frac{A_u}{A_t}\right)^{I_{max}-j}\right)\right)^m \right.\right.$$

$$\left.\left. \left(\sum_{k=1}^{i-1} \frac{1}{i-1}\left(1-\left(1-\frac{A_u}{A_t}\right)^{k-1}\right)\right)^{n-m}\right)$$

Evaluation Results: Clustering Coverage as a Function of r



(a) Low Node-Population Density



(b) High Node-Population Density

Summary

- We exploit parallelism and diversity in a novel fashion:
  - We let two different layers of clusters be formed in parallel to compose a significantly better coverage.
  - SCP applies complementary clustering policies to achieve a better clustering coverage by taking advantage of result diversity.
- The SCP framework provides mobile wireless hosts with a low-cost self-organizing capability which is the key to self-healing MANETs.

Future Work

- Formalize the SCP framework.
- Perform redundancy analysis: To view and utilize it in a positive way.
- Evaluate measures taking into account network dynamics.
- Allow nodes to move, fail, or die amid clustering.