Flow-based Energy Efficient Management of Wireless Mesh Networks

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Outline

1. Overview and Motivation
2. Problem Setting
3. Our Proposal
4. Performance Evaluation Results
5. Conclusion and Future Work
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Overview

![Overview Diagram]

Internet

Gateway

MAP

MAP
Overview

Central Controller

Gateway

MAP

Internet
Overview

Central Controller

Internet

Gateway

MAP

MAP
Overview
Overview

- Central Controller
  - Compute an Energy Efficient route
  - Flow route request

Internet

Gateway

MAP

MAP

- Overview and Motivation
- Problem Setting
- Our Proposal
- Evaluation
- Conclusion
Overview

Compute an Energy Efficient route
Flow route request
Flow route entries

Central Controller

Internet

Gateway
MAP
MAP
Overview

Overview and Motivation  Problem Setting  Our Proposal  Evaluation  Conclusion

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Central Controller
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Architecture

- An *Application* for a central controller
  - Use the global view of the network (links, flows)
  - Route new coming flows
  - Dynamic reconfiguration in case of:
    - User mobility
    - New user coming
    - User leaving
    - Topology
Problem Setting

GIVEN:

- A physical topology represented by the graph $G(V, E)$, which is described by the connectivity and interference matrices $M$ and $I$, respectively.
- A set of $m$ gateways in the WMN.
- A set $L$ of flows originating from clients, each one with its bandwidth demand $b_l$ and delay constraint $d_l$.
- The coverage matrix $A$ of MAPs.
- The previous attachment of clients and their flows’ routes

FIND:

- The optimal attachment of each user to one of the covering MAPs and the optimal routing of its corresponding flow that minimizes the network operation and reconfiguration costs, subject to QoS constraints (i.e., bandwidth and delay).
ILP Formulation

- Decision variables:
  - $w_{li}$ indicates whether the client originating the flow $l$ is attached to the MAP $i \in V$
  - $f_{e,k,l}$ indicates whenever the flow $l$ uses the channel $k$ on link $e$ on its route

- Energy consumption model of a MAP:

$$P_i = \begin{cases} 
  P_R & \text{If the MAP is used as a mesh router only} \\
  P_{AR} & \text{If the MAP is used as an AP and a mesh router} \\
  P_{AG} & \text{If the MAP is used as an AP and a gateway} \\
  P_{RG} & \text{If the MAP is used as a mesh router and a gateway} \\
  P_{ARG} & \text{If the MAP is used as an AP, a mesh route and a gateway} \\
  P_S & \text{In the MAP is in sleep mode.} 
\end{cases}$$
ILP Formulation

- **Objective Function to Minimize:**

\[
\alpha_E \sum_{i \in V} P_i + \alpha_S \sum_{i \in V} (y_i^+ c_i^+ + y_i^- c_i^-) + \alpha_R \sum_{i \in V} \sum_{l \in L} (r_{il}^+ c_{il}^+ + r_{il}^- c_{il}^-)
\]

- **Subject to:**
  - Satisfy clients bandwidth demands
  - Not violating clients' delay constraints
  - No routing over non-existing links
  - The proportion of utilization of interfering links should be less than one
  - Not exceeding links capacities
  - Not exceeding gateways capacities
Limitations

- Changes may be too frequent
  \[\Rightarrow\] Computation overhead
  \[\Rightarrow\] Instability in the network (QoS degradation)

- The ILP is NP-Hard
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Our Proposal for Solution Approximation

Once a flow is received, find a routing path that minimizes the energy consumption (without reconfiguring existing flows)

⇒ Reduce the frequent reconfigurations
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- We use a modified version of the shortest path algorithm
- The cost is not the number of hops but the additional amount of needed power to route the flow
- Choose among $K$ alternative paths, the path with the minimum additional needed power
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Periodically (Every period of time $t$) reconfigure using an Ant Colony based approach
- Ant Colony Energy Efficient Online Flow Routing (AC-OFER)
- Given $K$ alternative paths for every flow (client)
- Use the artificial ants to find a near optimal solution
⇒ Reduce the computation time
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Test setting

- **Mesh Network:**
  - Grid topology with random gateways
    - Small topologies: 25 nodes and 3, 4 gateways
    - Large topologies: 100 nodes and 7 – 10 gateways
  - Wireless link capacity of 54 Mbps
  - Single channel

- **Flows:**
  - Uniform bandwidth demand between 1 and 10 Mbps
  - Poisson arrivals with rate $\lambda$ and exponential lifetime of mean 1.5 hours
  - Uniform location for client
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- **Baseline:** Shortest Path, Minimum residual capacities routing metric, Load Balancing
Energy Consumption Results (25 nodes and 3 gateways)

- AC-OFER reduces energy consumption

**Total Energy Consumption**

**Power consumption over time**

\(\lambda = 25\) requests/hour
Acceptance Ratio Results (25 nodes and 3 gateways)

- AC-OFER achieves higher acceptance ratio

<table>
<thead>
<tr>
<th></th>
<th>AC-OFER</th>
<th>MRC</th>
<th>Shortest Path</th>
<th>Load Balancing</th>
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<tbody>
<tr>
<td>Time (hours)</td>
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<td>Acceptance Ratio</td>
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Light traffic load ($\lambda = 4$)

Medium traffic load ($\lambda = 25$)
AC-OFER reduces the energy consumption but increases a bit the average path length.
APs Only Network results ($\lambda = 20$ requests/hour)

- AC-OFER reduces energy consumption for different network sizes

![Energy consumption chart](image)
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Conclusions and Future Work

**Conclusions:**
- Online flow-based routing approach
- Compliant with SDN
- Meta-heuristic approach

**Future Work:**
- Power control in the WMN for interference mitigation and energy efficiency
- Reconfiguration time computation
AC-OFER Algorithm

Algorithm 1 AC-OFER algorithm

**IN:** WMN with routed flows (i.e., previous routes solution)
**OUT:** A new routes solution (One path for each flow)

Set Parameters: \( q_0, \alpha_A, \beta_A, Q \)

Initialize pheromone trails and best_solution to the previous solution

for \( nb = 1 \rightarrow \) Number of Iterations do

\[//\text{Construct Ant Solutions}\]

for all ant in \( A_{\text{max}} \) do

\[
\text{current_solution} \leftarrow \{\}\]

for \( l = 1 \rightarrow \) Number of flows do

\[p \leftarrow \text{Random}(0..1)\]

if \( p < q_0 \) then

\[
j = \text{Argmax}_{k \in N_l} \left( \tau_{lk}^{\alpha_A} \times \eta_{lk}^{\beta_A} \right)\]

else

Choose path \( j \) according to \( P_{lj} \) given in (13)

end if

Add the \( j^{th} \) path for flow \( l \) to current_solution

end for

if current_solution is better than best_solution then

best_solution \( \leftarrow \) current_solution

end if

end for

\[//\text{Update Pheromones for all flows l}\]

\[\tau_{lj} \leftarrow (1 - \rho)\tau_{lj} //\text{Evaporate all pheromones}\]

if current_solution is the best solution for the current iteration

And \( j^{th} \) path is selected for flow \( l \) then

\[\tau_{lj} \leftarrow \tau_{lj} + \Delta_{lj}^{\text{best}}\]

end if

end for

Return best_solution