Flow-based Energy Efficient Management of Wireless Mesh Networks

Ahmed Amokrane[1], Rami Langar[1], Raouf Boutaba[2], Guy Pujolle [1]

[1] LIP6, Pierre and Marie Curie University, Paris 6, France

[2] University of Waterloo, Ontario, Canada

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Outline

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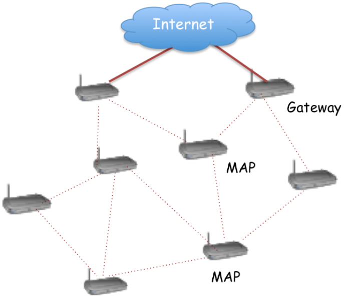
2. Problem Setting
3. Our Proposal
4. Performance Evaluation Results
5. Conclusion and Future Work

Overview



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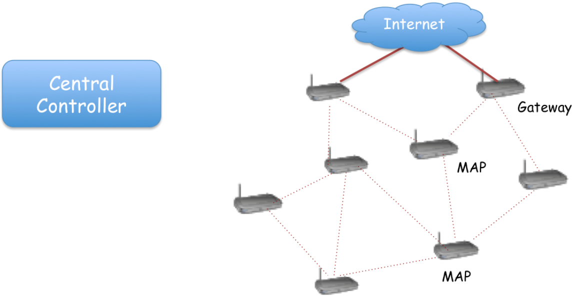

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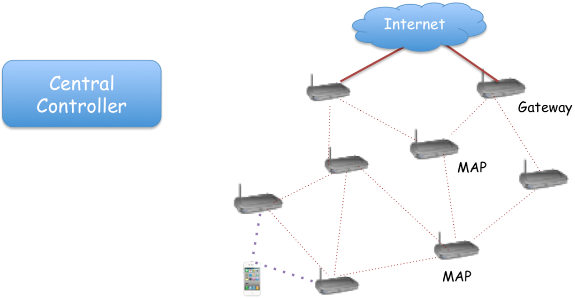

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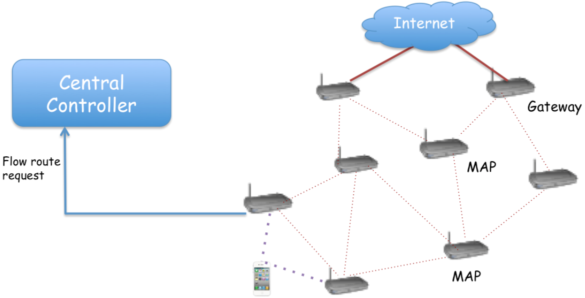
Central Controller
Flow route request
Internet
Gateway
MAP
MAP

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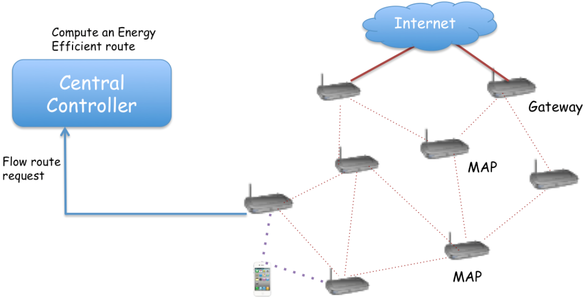
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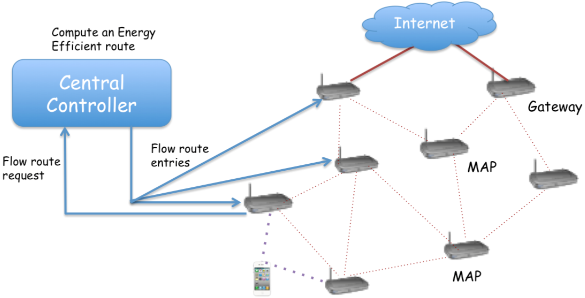

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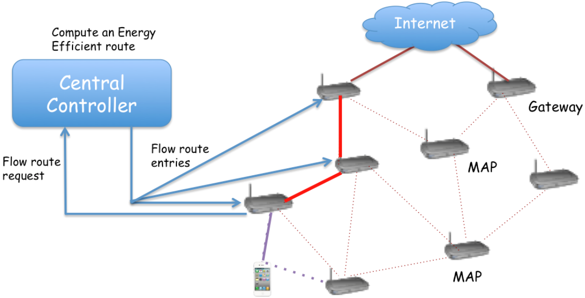
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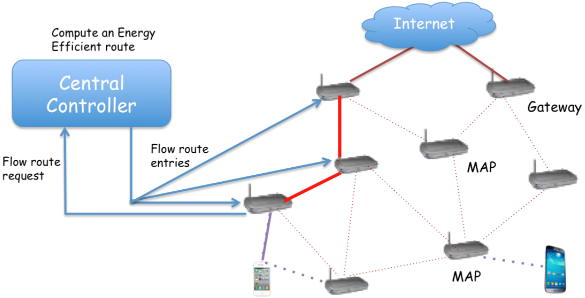

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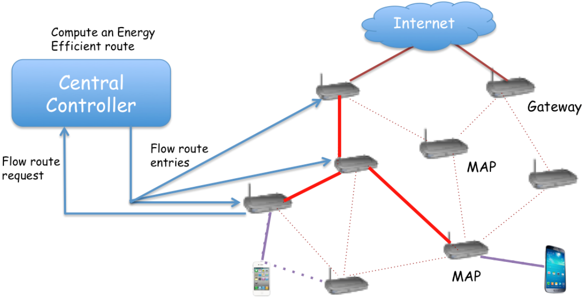
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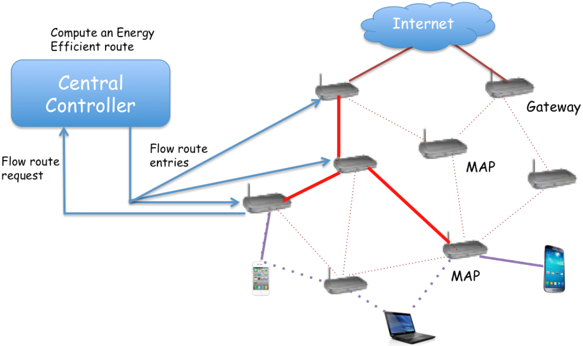

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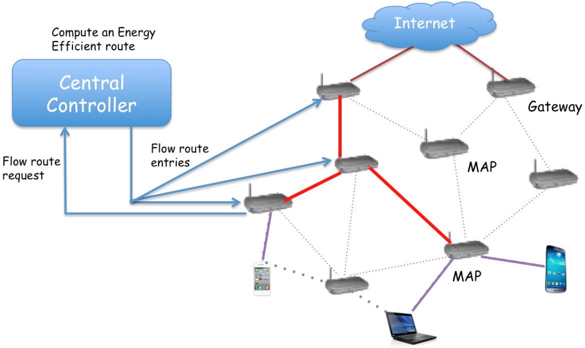
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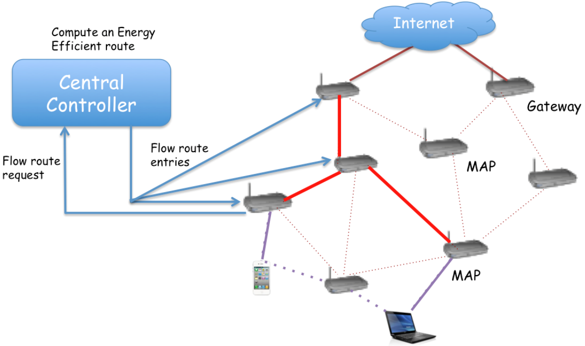
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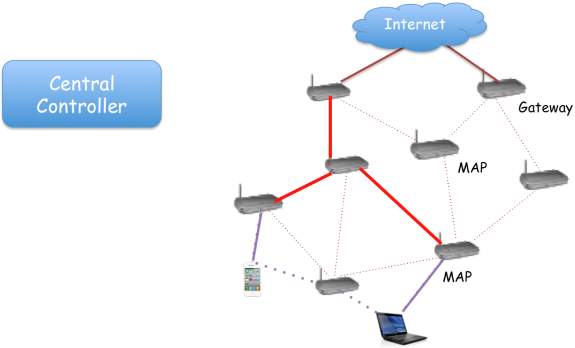

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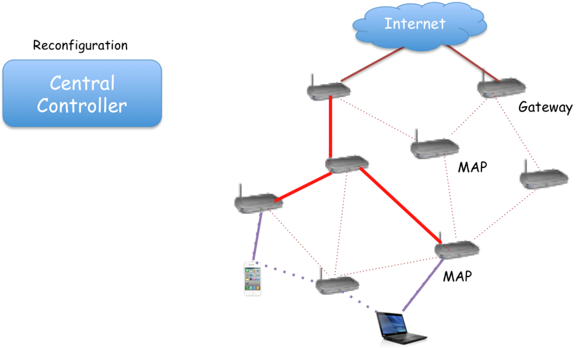
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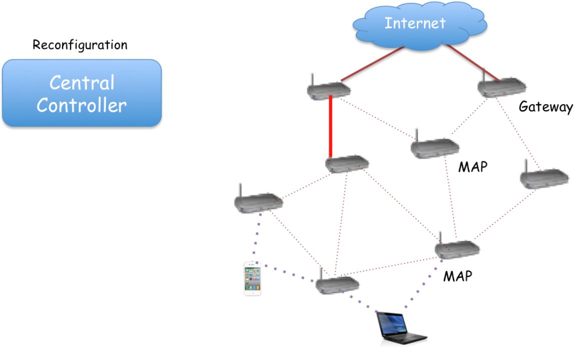
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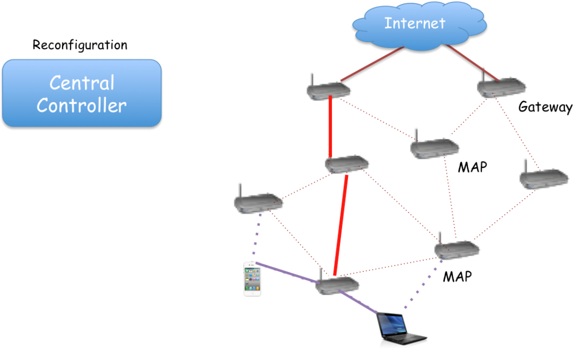
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Outline

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:

$$\underbrace{\alpha_E \sum_{i \in V} P_i}_{\text{Energy Cost}} + \underbrace{\alpha_S \sum_{i \in V} (y_i^+ cs_i^+ + y_i^- cs_i^-)}_{\text{Switching on/off cost}} + \underbrace{\alpha_R \sum_{i \in V} \sum_{l \in L} (r_{il}^+ cr_{il}^+ + r_{il}^- cr_{il}^-)}_{\text{Flow Rerouting Cost}}$$

- 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 the minimize the energy consumption (without reconfiguring existing flows)
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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

  $\Rightarrow$ Reduce the computation time

Outline

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 λ and exponential lifetime of mean 1.5 hours
  - Uniform location for client

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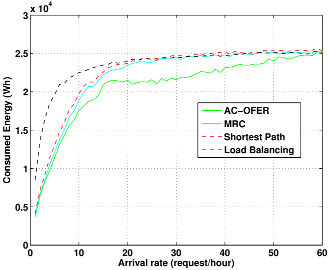
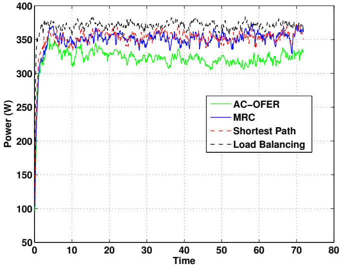
- Baseline: Shortest Path, Minimum residual capacities routing metric, Load Balancing

Energy Consumption Results (25 nodes and 3 gateways)

- AC-OFER reduces energy consumption



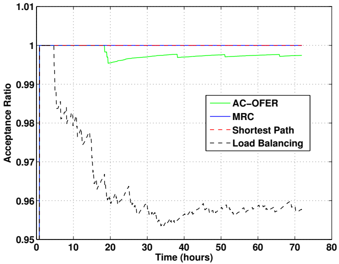
Total Energy Consumption



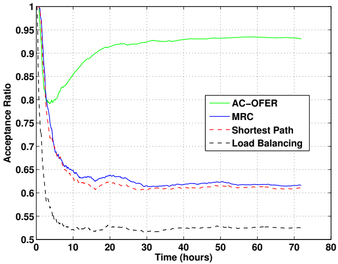
Power consumption over time ($\lambda = 25$ requests/hour)

Acceptance Ratio Results (25 nodes and 3 gateways)

- AC-OFER achieves higher acceptance ratio



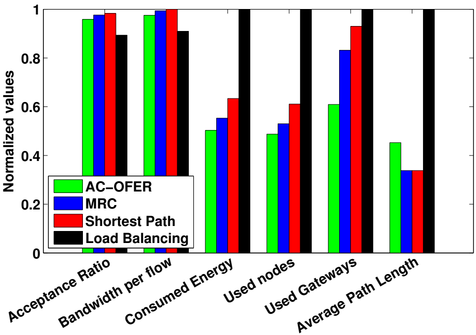
Light traffic load ($\lambda = 4$)



Medium traffic load ($\lambda = 25$)

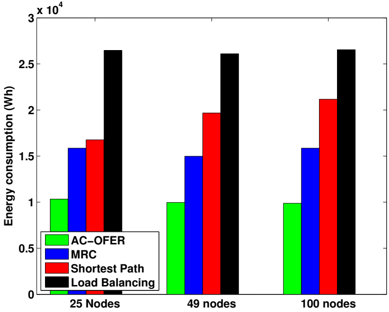
Summary of different metrics (100 nodes and 9 gateways)

- 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



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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, α_A, β_A, Q
Initialize pheromone trails and best_solution to the previous solution
for $nb = 1 \rightarrow$ Number of Iterations **do**
  //Construct Ant Solutions
  for all ant in A_{max} **do**
    current_solution $\leftarrow \{\}$
    for $l = 1 \rightarrow$ Number of flows **do**
      $p \leftarrow Random(0..1)$
      if $p < q_0$ **then**
        Choose path j among the K paths where
        $j = \text{Argmax}_{k \in N_l} \left(\tau_{lk}^{\alpha_A} \times \eta_{lk}^{\beta_A} \right)$
      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
  //Update Pheromones for all flows l
  $\tau_{lj} \leftarrow (1-\rho)\tau_{lj}$ *//Evaporate all pheromones*
  if current_solution is the best solution for the current iteration And j^{th} path is selected for flow l **then**
    $\tau_{lj} \leftarrow \tau_{lj} + \Delta_{lj}^{best}$
  end if
end for
Return best_solution