On Multi-Gateway Association in Wireless Mesh Networks

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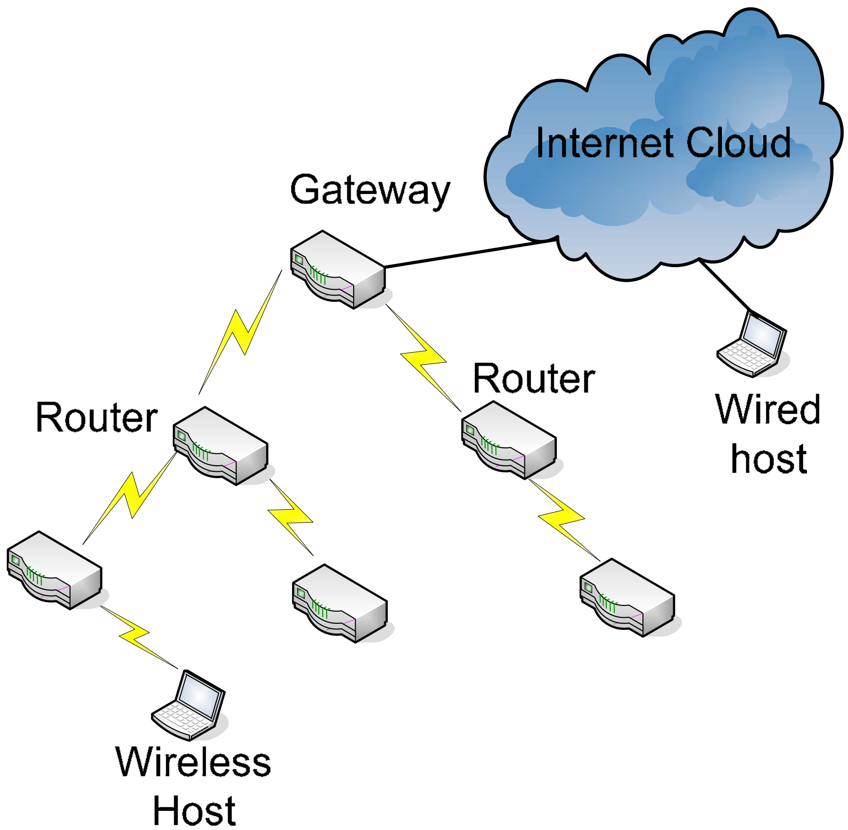
Wireless Mesh Networks

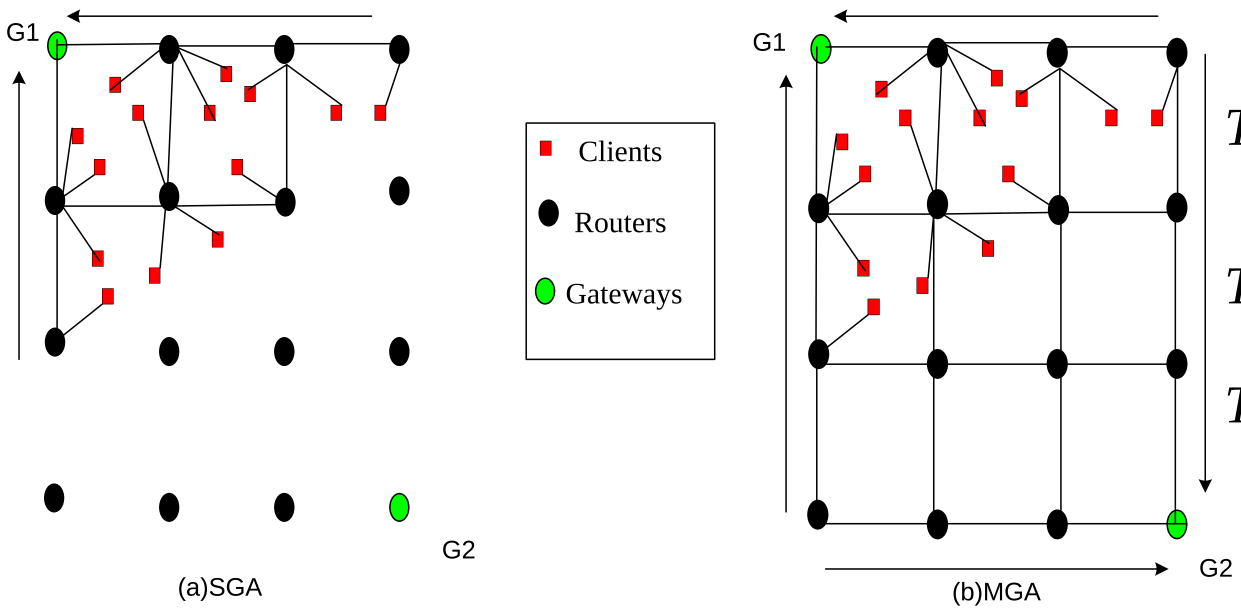
- Characteristics
  - Multi-hop with a static routing infrastructure
  - Several applications in military and commercial scenarios such as hospital, residential broadband networks
  - Gateway Association – establishing a connection to the wired internet(through a gateway)
- Challenges
  - capacity, security and fairness



Motivation

- Default model
  - Single Gateway Association [Wimesh2005].
    - simple model
    - leads to several issues such as single-gateway bottleneck, fairness, security ;etc
  - What if we move away from this model?
- Proposed Model
  - Multi-Gateway Association (MGA)
    - every client can use more than one gateway simultaneously
- Focus of present work
  - highlight the benefits & challenges of MGA
  - develop a (centralized) solution suite to achieve anticipated benefits
  - evaluate solution performance using simulations

Benefits of MGA-Capacity(1/4)



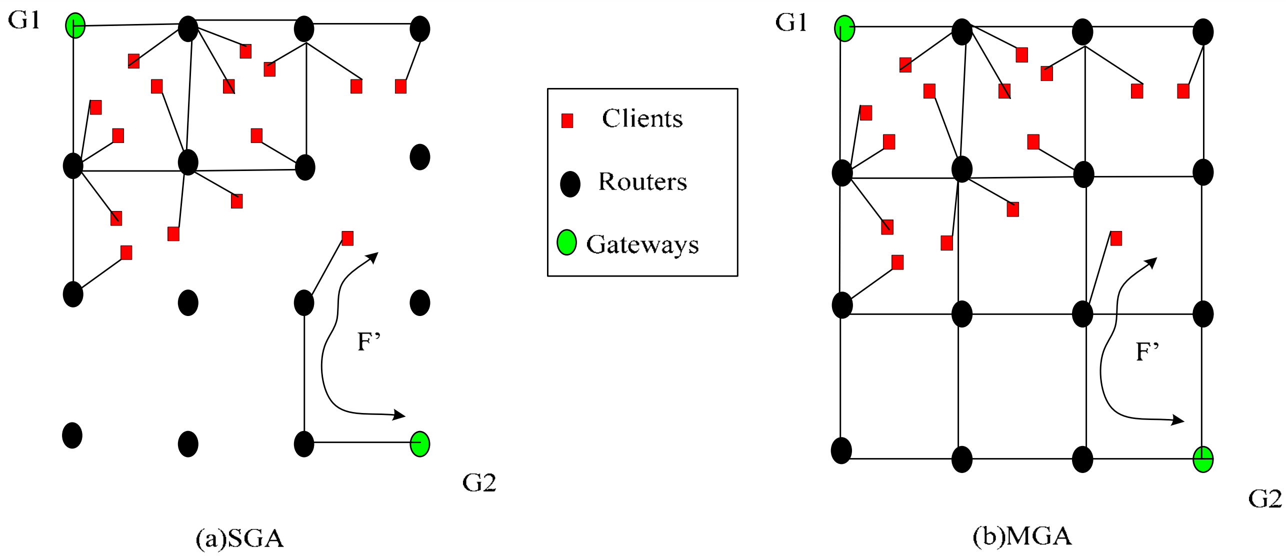
$$T_{SGA} = \sum_{i=1}^{g} \min(GL_i, GC_i)$$

$$T_{MGA} = \min\left(\sum_{i=1}^{g} GL_i, \sum_{i=1}^{g} GC_i\right)$$

$$T_{MGA} \geq T_{SGA}$$

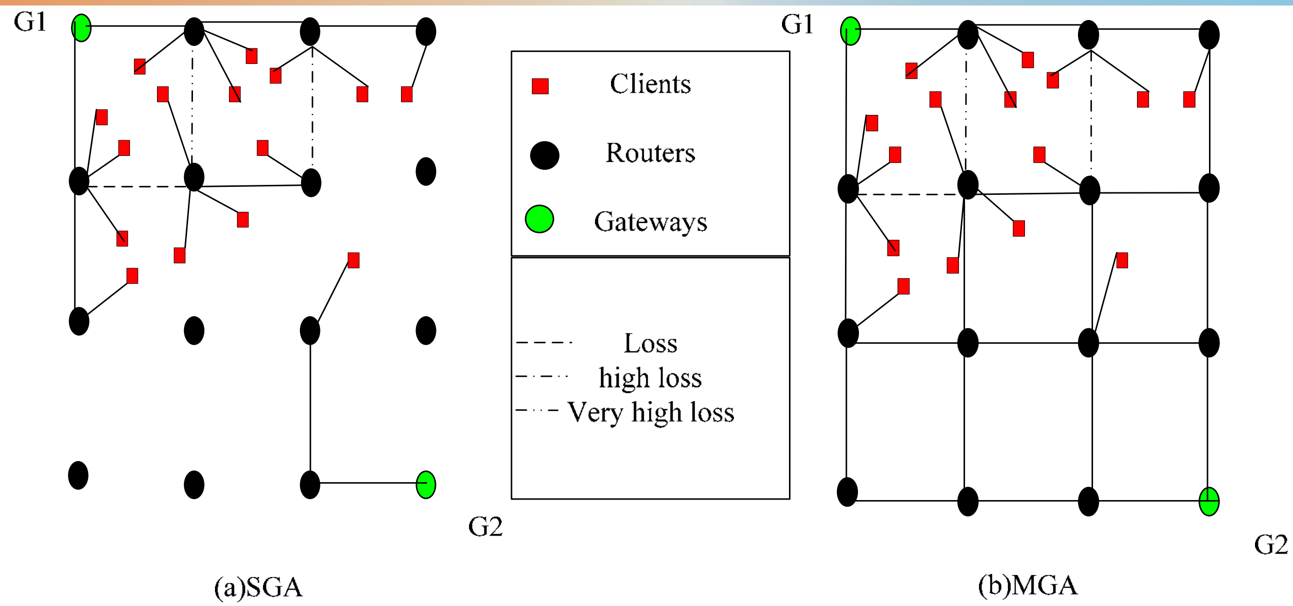
- Capacity
  - Better resource utilization
  - Ideally when the network load is below throughput capacity

Benefits of MGA-Fairness (2/4)



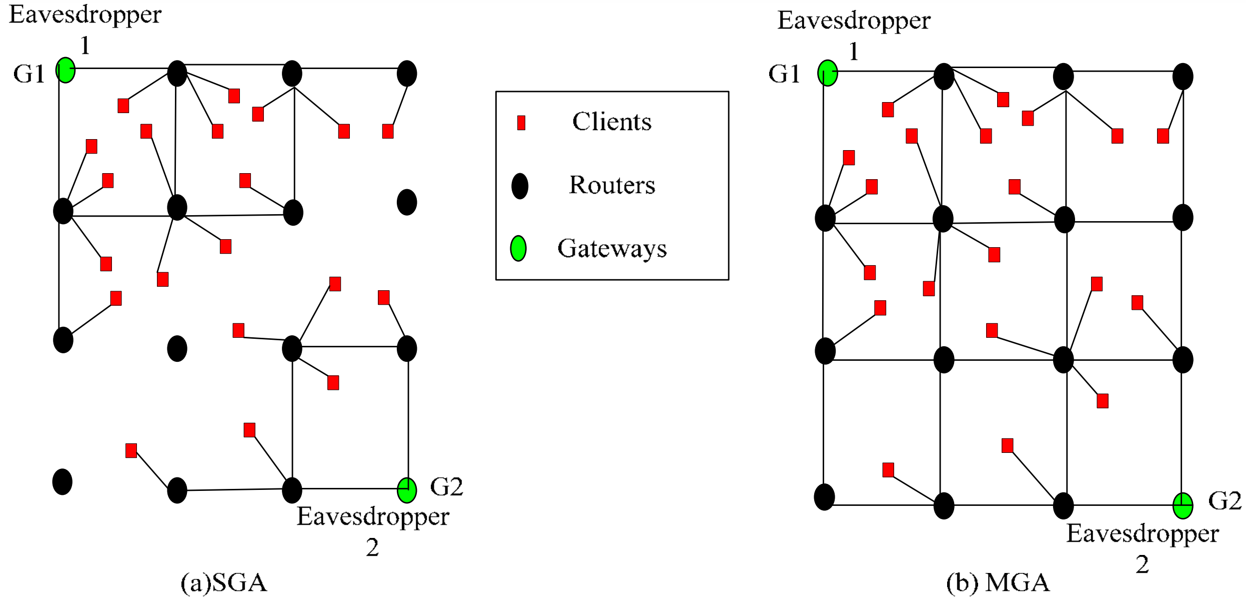
- Fairness
  - Problems due to
    - Uneven geographic distributions – nearness to gateway
    - Uneven traffic distribution – differently loaded gateways
  - MGA improves fairness by more uniform distribution of loads and using aggregate resources than single gateway resources

Benefits of MGA-Diversity (3/4)



- Diversity
  - Types of loss:
    - Hard losses- failure of gateway
    - Soft losses- space dependent channel loss, buffer drops;etc
  - Path, gateway diversity possible with MGA

Benefits of MGA-Security (4/4)



- Security
  - Problem:
    - Gateway - a single aggregation point
    - Interception around gateway exposes the wireless network
  - MGA
    - Makes the eavesdropper's task more difficult
    - Reduces the number of intercepted packets

Challenges

- Architectural model
  - Requirement of splitting for downstream and reassembly for upstream
- Gateway characterization
  - loss , delay and throughput characteristics of the paths from each client to each gateway
- Gateway Association
  - How many gateways to associate with?
  - Which gateways to associate with?
- Scheduling
  - which packet to send at what time instant so that effective aggregation and in-sequence delivery occur?

Gateway Association Algorithm

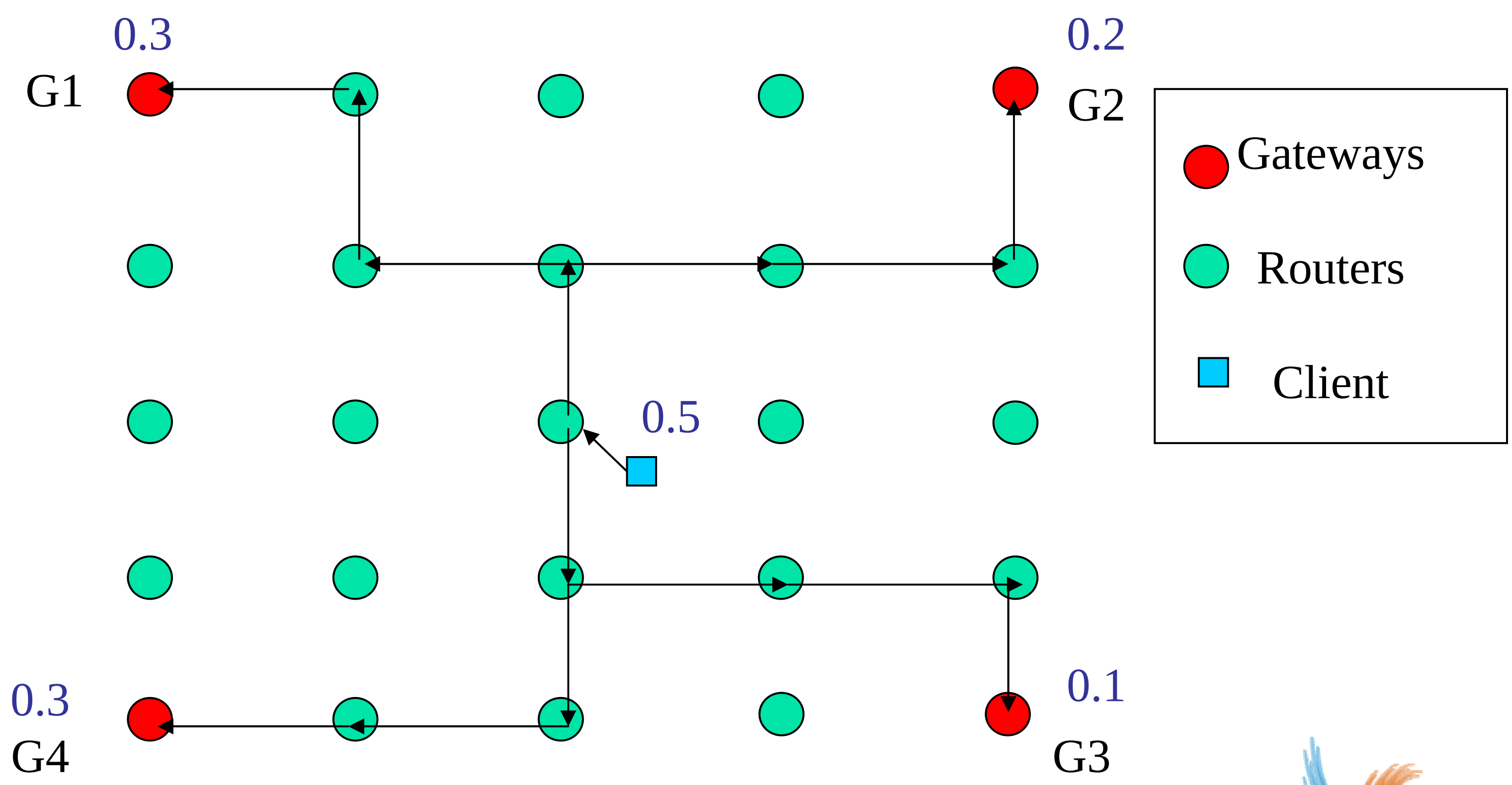
- Overview
  - Greedy centralized algorithm to determine associations and rates
  - Maximize aggregate throughput subject to max-min fairness
- Algorithm
  - Step 1: Path Computation
    - Compute shortest paths to each gateway from the client
  - Step 2: Bandwidth Computation
    - Compute available bandwidths on each path using the flow graph
  - Step 3: Gateway Decision
    - Identify the number of gateways and the exact gateways to associate with

Gateway Decision Details

- Is load less than sum of available bandwidths?
  - Yes: allot bandwidth in a greedy manner (in descending order of available bandwidths)
  - No: For the excess load
    - Compute maximum degree bottlenecks on paths to gateways
    - Identify the set of flows which contends or intersects to the maximum
    - Allot unit bandwidth from maximum rate flow to the new flow one the maximum bottleneck path
    - Terminate if load is allotted or max-min allocation is reached

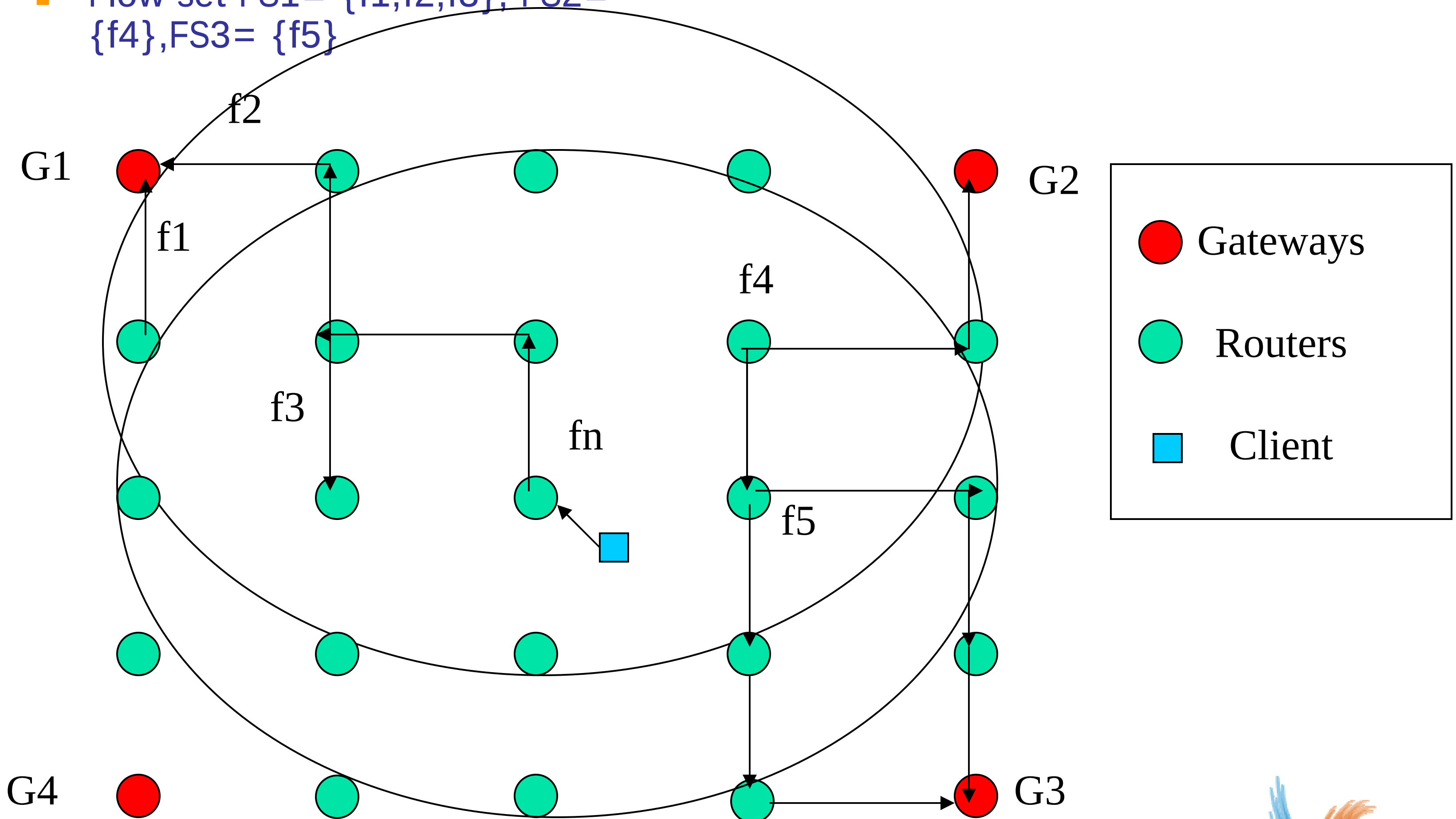
Gateway Association Algorithm

- Illustration
  - Step 1 / Step 2
    - Client with load of 0.5 computes paths and identifies gateway statistics



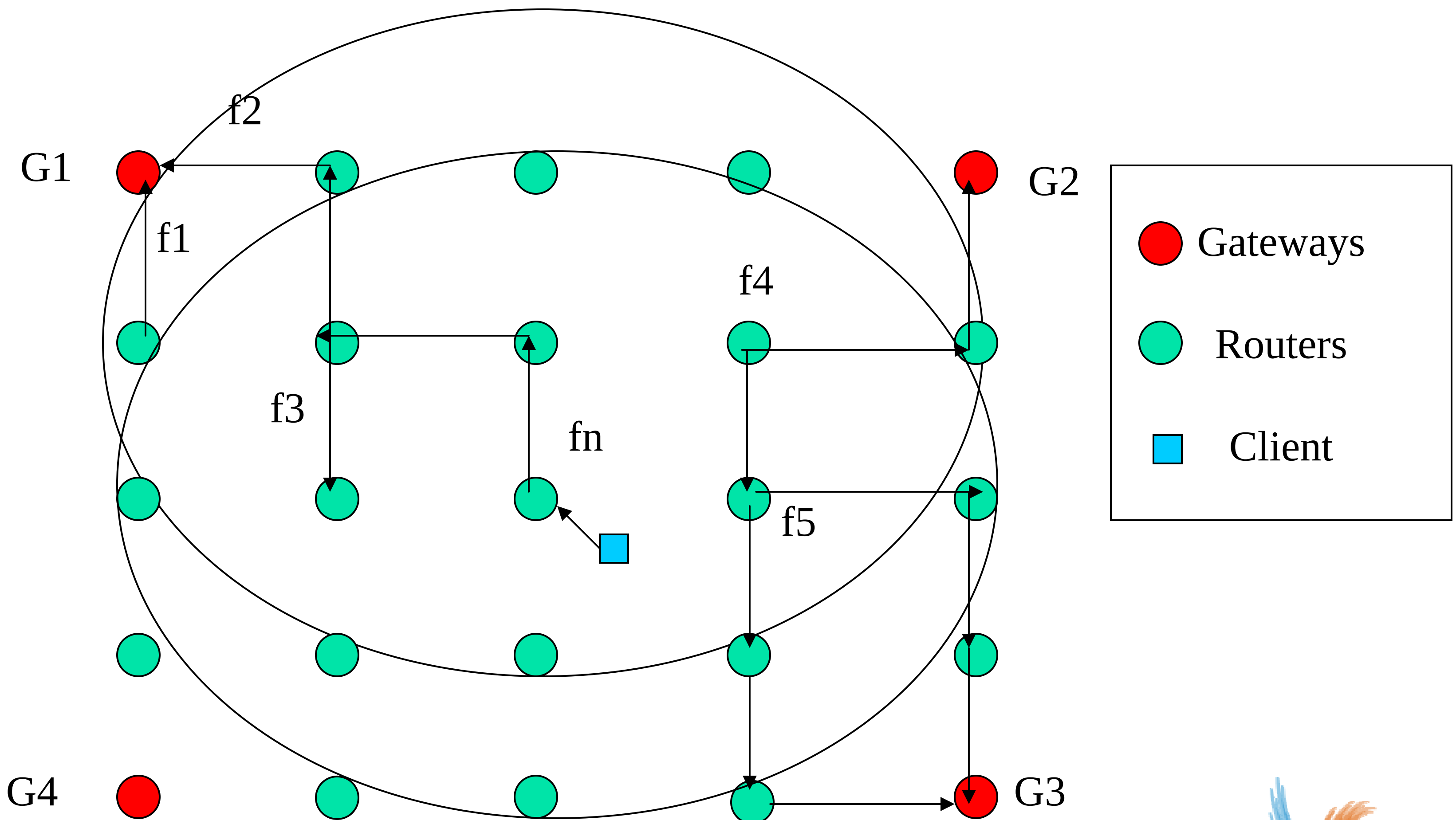
GAA-Flow sets

- Illustration of step 3
  - Flow set FS1= {f1,f2,f3}, FS2= {f4},FS3= {f5}



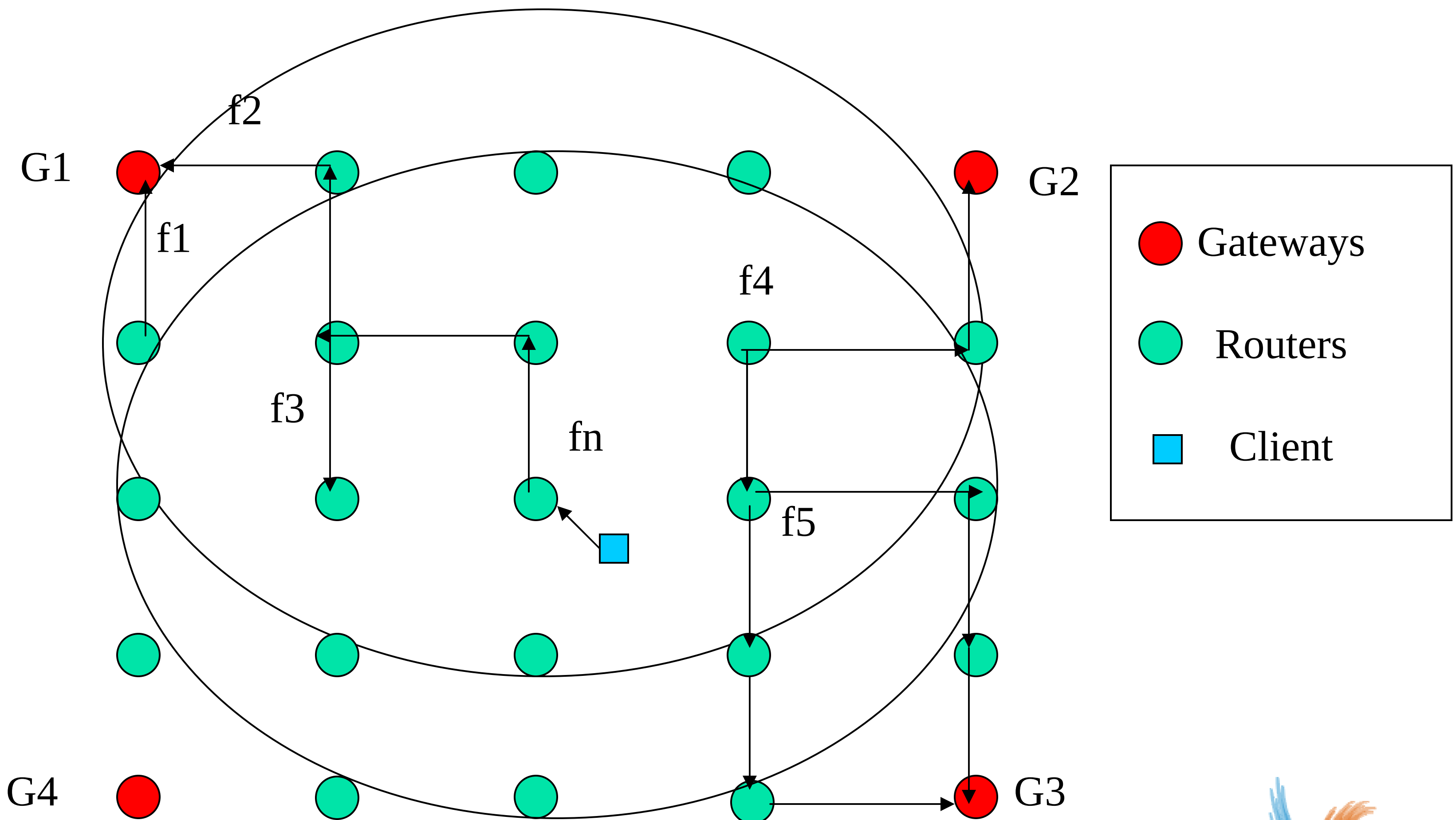
Gateway Association Algorithm

OFS={f1,f2,f3,f4,f5}



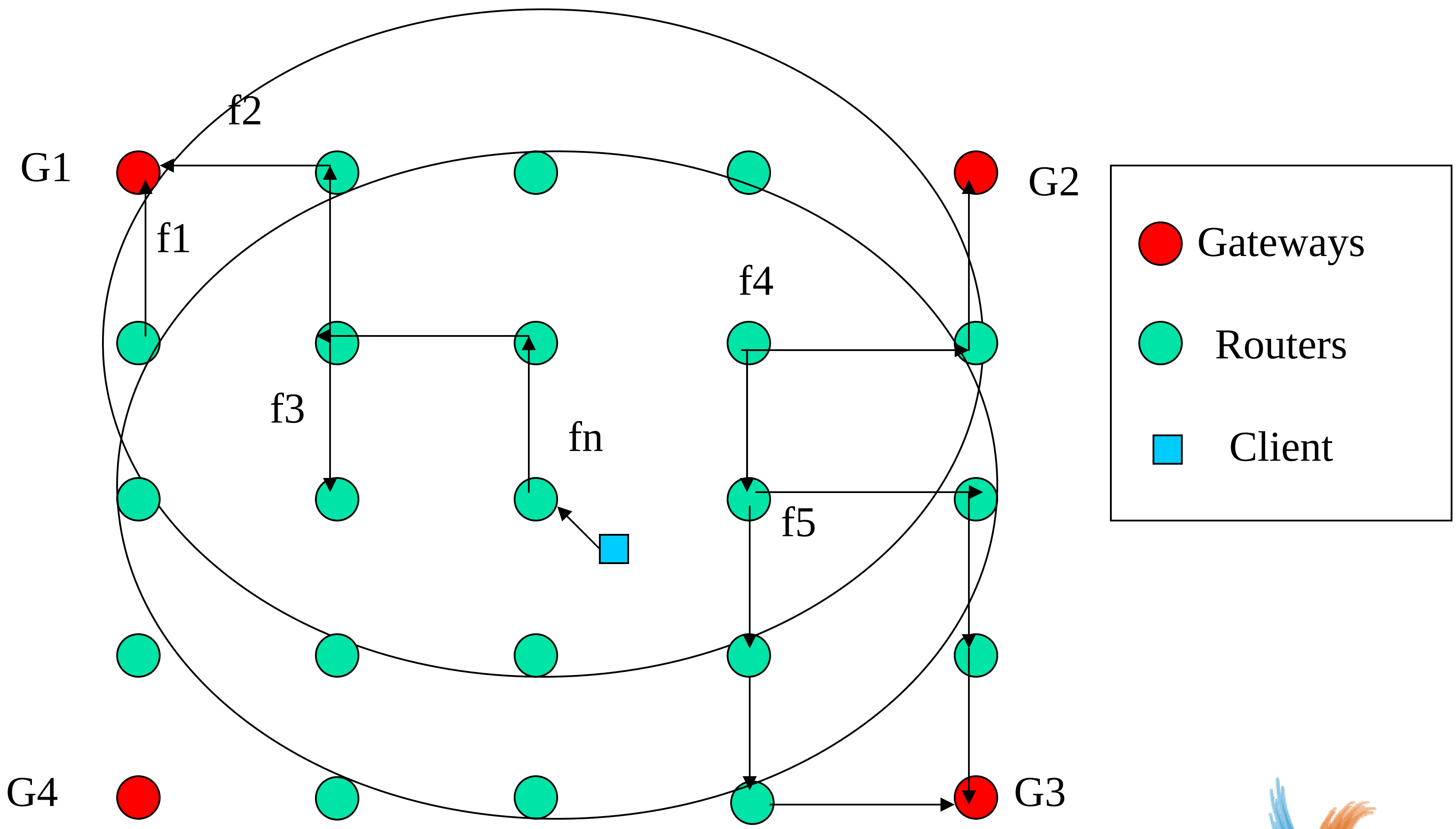
Gateway Association Algorithm

- Let f4 be the maximum rate flow and Rate(f4,2) = 0.1 ; Rate(f4,3) =0.1



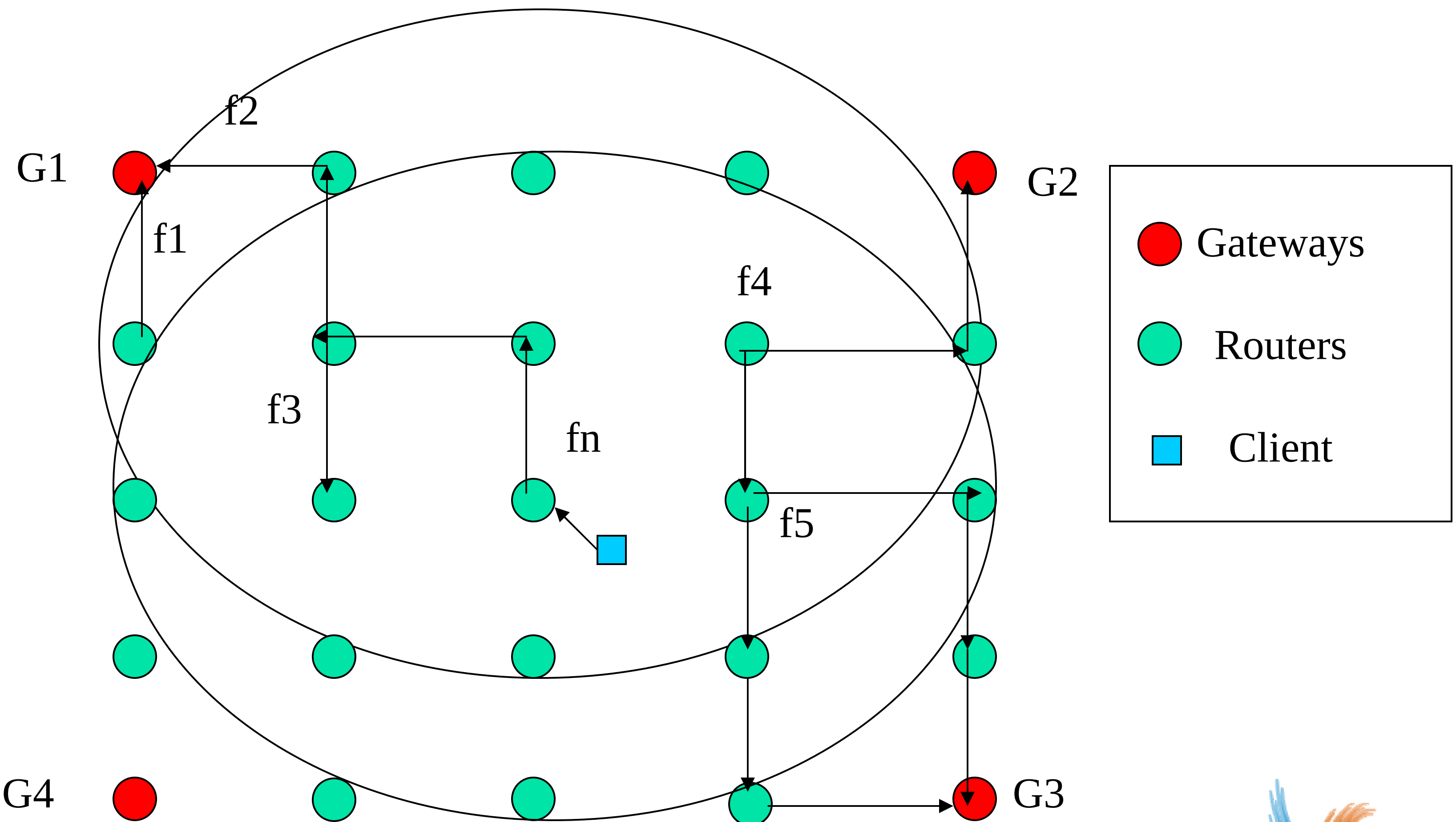
Gateway Association Algorithm

- New rates: Rate(f4,2) = 0.05, Rate(f4,3) = 0.1; Rate(fn,2) = 0.05



Gateway Association Algorithm

- Continues till max-min allocation or fn's requirement

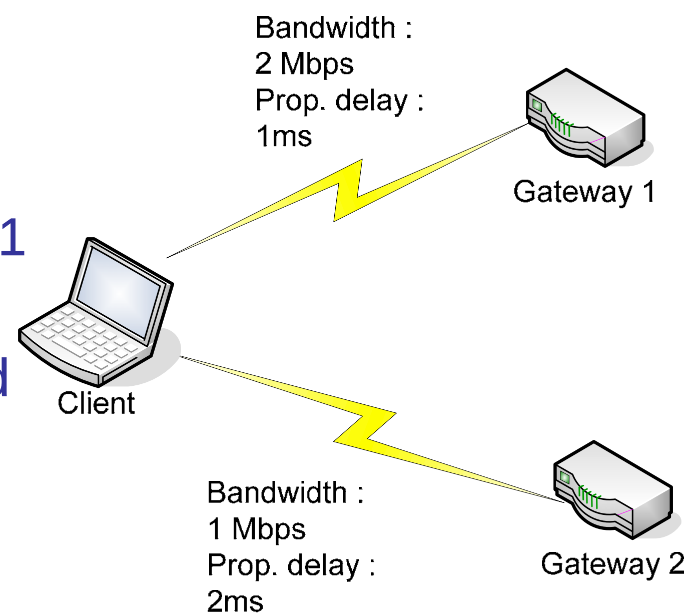


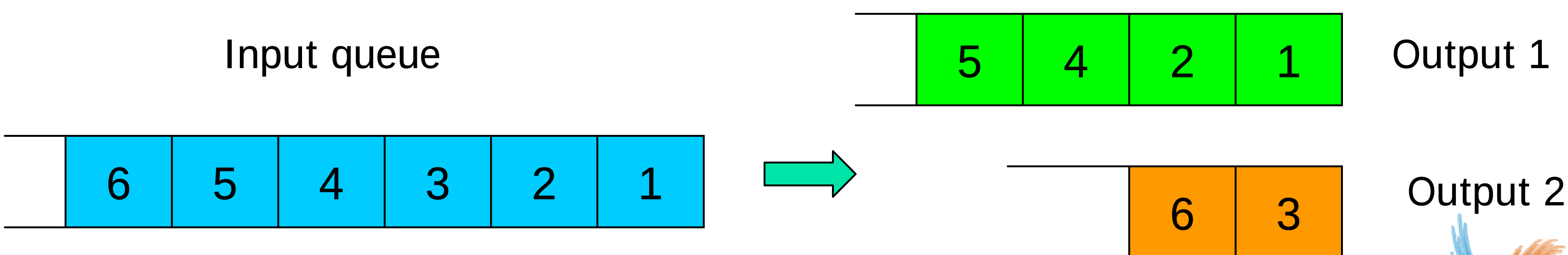
Scheduling - Overview

- Goal
  - enable effective aggregation and prevent out of order delivery
- Procedures
  - Step 1:Window calculation
    - Calculate the number of packets to each of the associated gateways
    - Uses integral values of normalized delay ratios.
  - Step 2:Ordering
    - Calculate reception times as transmission time + other delays
    - Tag each packet with a 2-tuple (seq.no, expected reception time)
      - Expected reception time for packets of the same destination = Propagation delay + k*Transmission delay (where k is its position in the destination queue)
    - Sort in ascending order of reception time

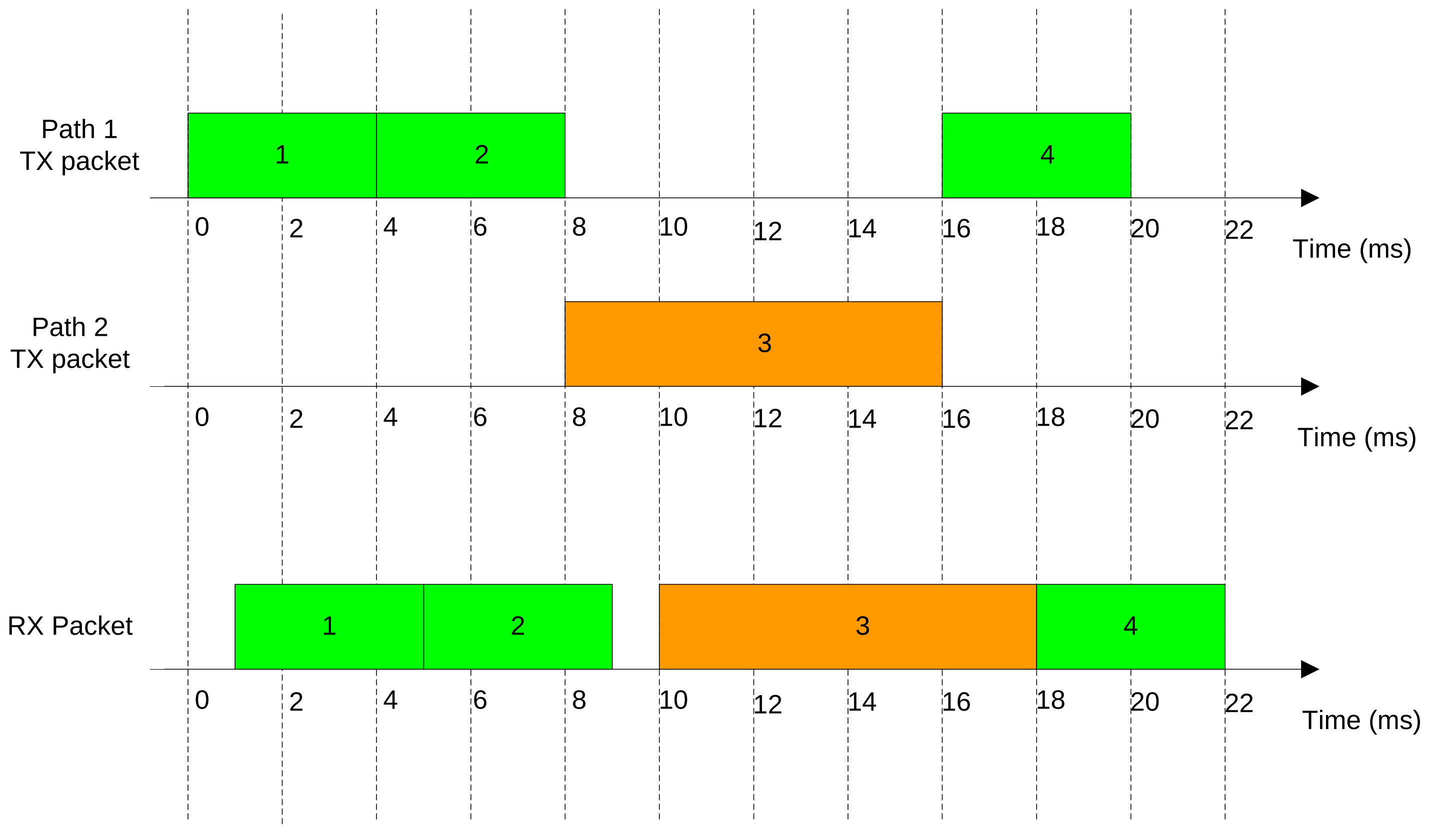
Scheduling Illustration

- Window calculation
  - The total delays (Assuming a packet size of 1000 bytes) are
    - D1= 4 ms + 1ms = 5ms
    - D2= 8ms + 2ms = 10ms
  - Normalized integral delays are 2 and 1
- Ordering
  - Generate 2-tuples (seq. no , expected reception time) for example (1,5) (2,9) (3,10)





Scheduling Instants



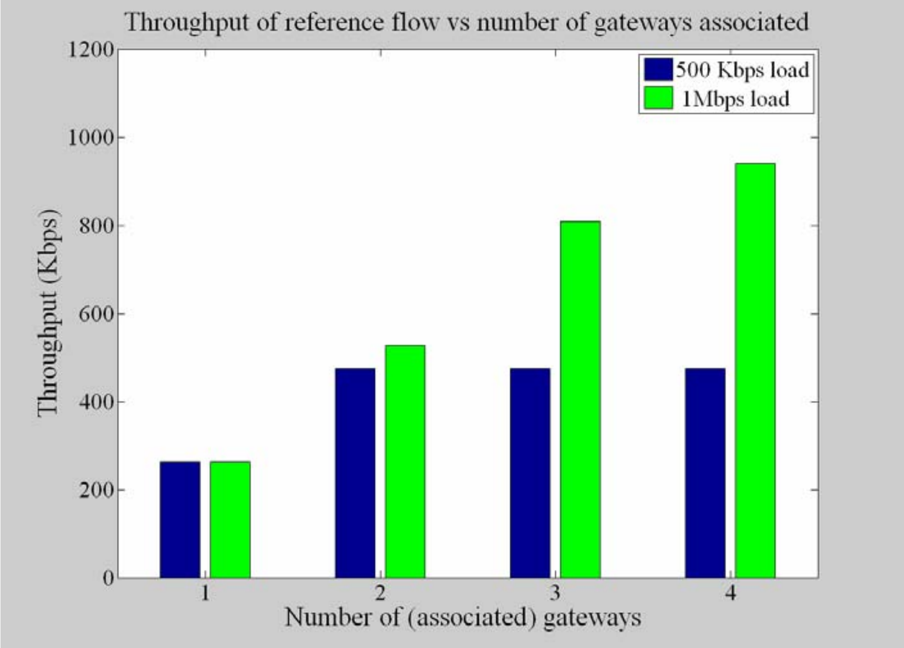
- In-sequence delivery, if delays are correct

Performance evaluation - Setup

- Ns2 simulator
- 1000 m * 1000 m grid
- 4 gateways at (200,200) , (200,900) , (900,200) and (900,900)
- 21 Routers uniformly deployed along with 10 clients
- Each client has a traffic demand of 500 Kbps
- Application – CBR
- Transport layer- UDP
- Routing- Static Shortest path
- MAC - Ideal Flow Scheduling
- PHY – Wireless Phy at 915 MHz

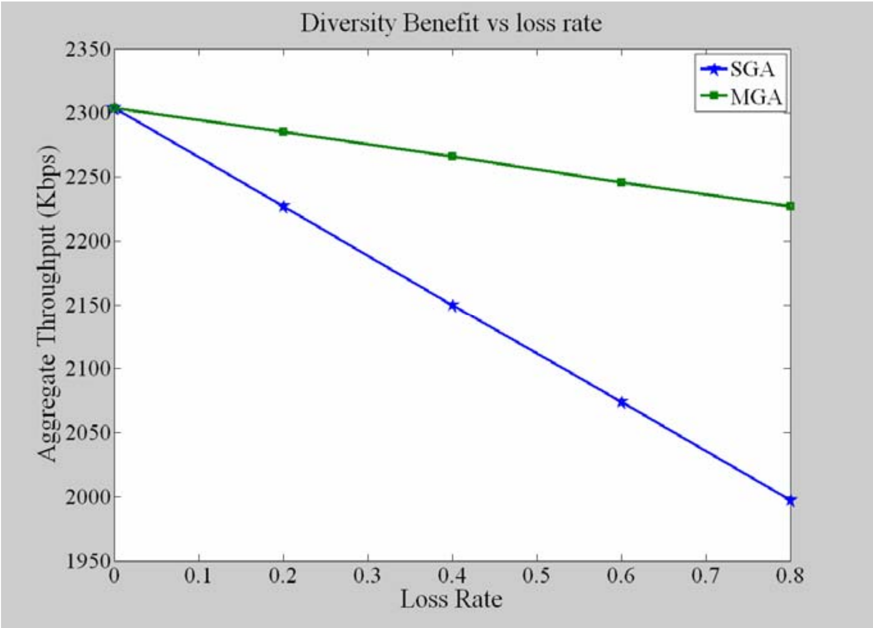
Throughput Improvements

SGA	MGA	benefit
2.5Mbps	2.76 Mbps	10.4%



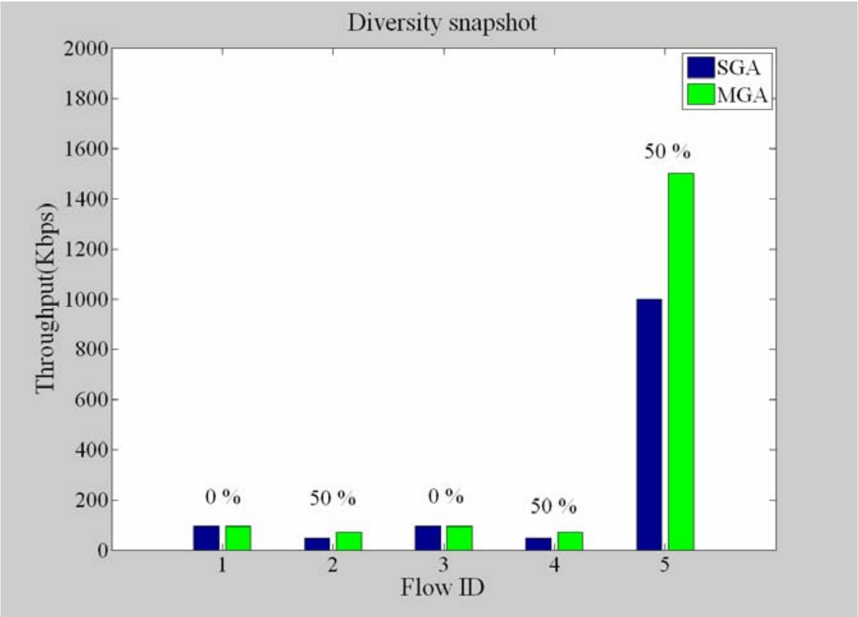
- Average case
  - improvement around 10% .
- Effect of load
  - Single reference client at the center and other clients outside the grid of gateways
  - Almost linear improvement in throughput gain with number of associations
  - Load also decides the gains possible

Diversity Benefit (1/2)



- A single loss module at gateway 0 (i.e. at (200,200))
- Simulated path loss rate at gateway
- Averaged over 10 seeds for each loss rate
- MGA has lesser degradation and rate of degradation with losses

Diversity Benefit (2/2)



- For a fixed 50% loss rate at one gateway
- Loads are 100,100,100,100, 2000 Kbps
- Flows achieve 50% benefit in throughput
- Only flows associated with lossy gateway show improvement

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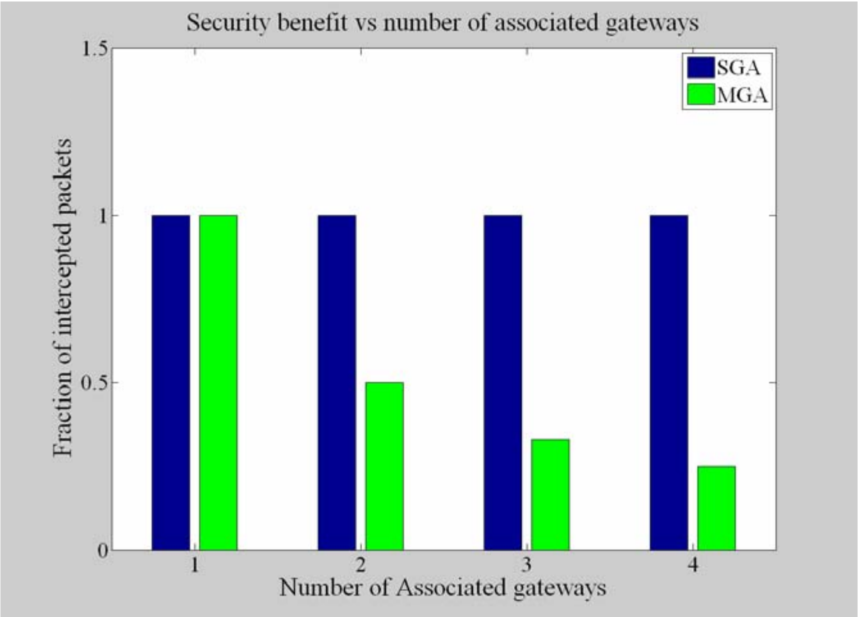
Security Benefit (1/2)



- Security benefit increases with number of gateways
- Fraction of intercepted packets of each flow with increasing associations allowed
- Total interception by eavesdropper assumed
- Trend is same for all flows as the number of associations is same
- Near ideal benefit ratios

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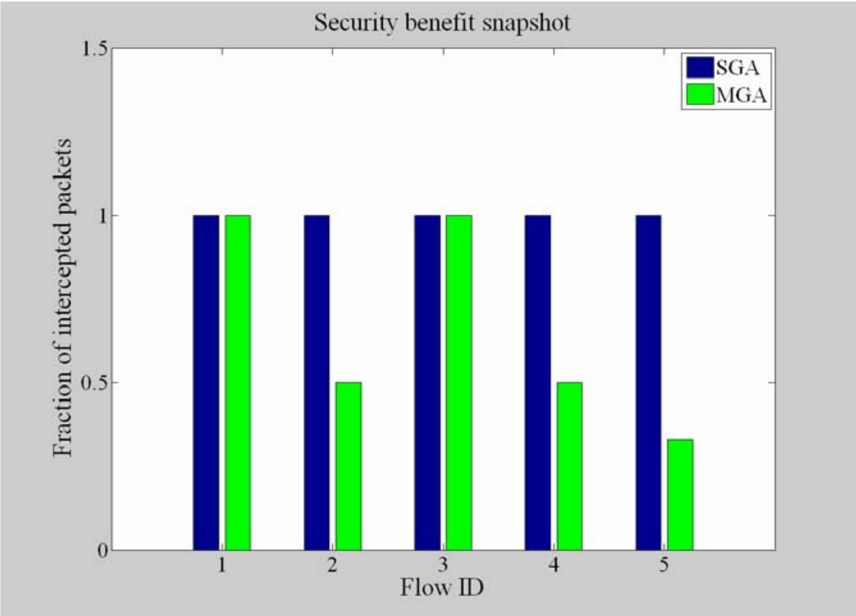
Security Benefit (2/2)



- Practical case of, providing security without significant (<10%) capacity degradation
- The associations are 1,2,1,2,3 for flows 1 to 5 respectively
- Near ideal benefits obtained for flows that perform multi-association

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Related Work

- Wireless Mesh networks
  - Dual association of clients with routers for optimizing broadcast load [Wimesh 2005]
  - Capacity of mesh networks [Mobicom 2005]
  - Security challenges in wireless networks [Mobicom 2001]
- Multiple Connections
  - pTCP : Transport solution suite for Managing multiple TCP connections [Mobicom 2002]
  - R^2CP : Receiver Centric Transport Protocol allows aggregation of bandwidth [Mobicom 2003]

Conclusions

- Showed that the MGA model has many benefits
- Identified challenges in leveraging the benefits of multi-gateway association
- Designed centralized algorithms for gateway association and scheduling
- Evaluated the association algorithm through simulations
- Multi-gateway association has benefits, but leveraging them requires non-trivial algorithm development
- Further neither a single gateway nor all gateway association can bring the best benefits

Future work

- Evaluate the scheduling algorithm and the effect of TCP flows
- Identify all the drawbacks of MGA
- Evaluate the different factors that impact the achievable benefits
- Design gateway characterization algorithms to obtain network information and decide in a distributed manner
- Identify a more general framework in which associations are decided to support the desired levels of capacity, diversity and security simultaneously

Thank You