Groupage du trafic

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Introduction

- WDM NETWORKS
  - 1 wawelength = up to 40 Gb/s
  - 1fiber = hundred of wawelengths = Tb/s
- Idea
  Group (combine, pack,agregate, ...)
  low speed components (signals,traffics streams,...)
  into higher components
- Goal
  - Better use of bandwith
  - Minimize the network (in particular equipment) cost

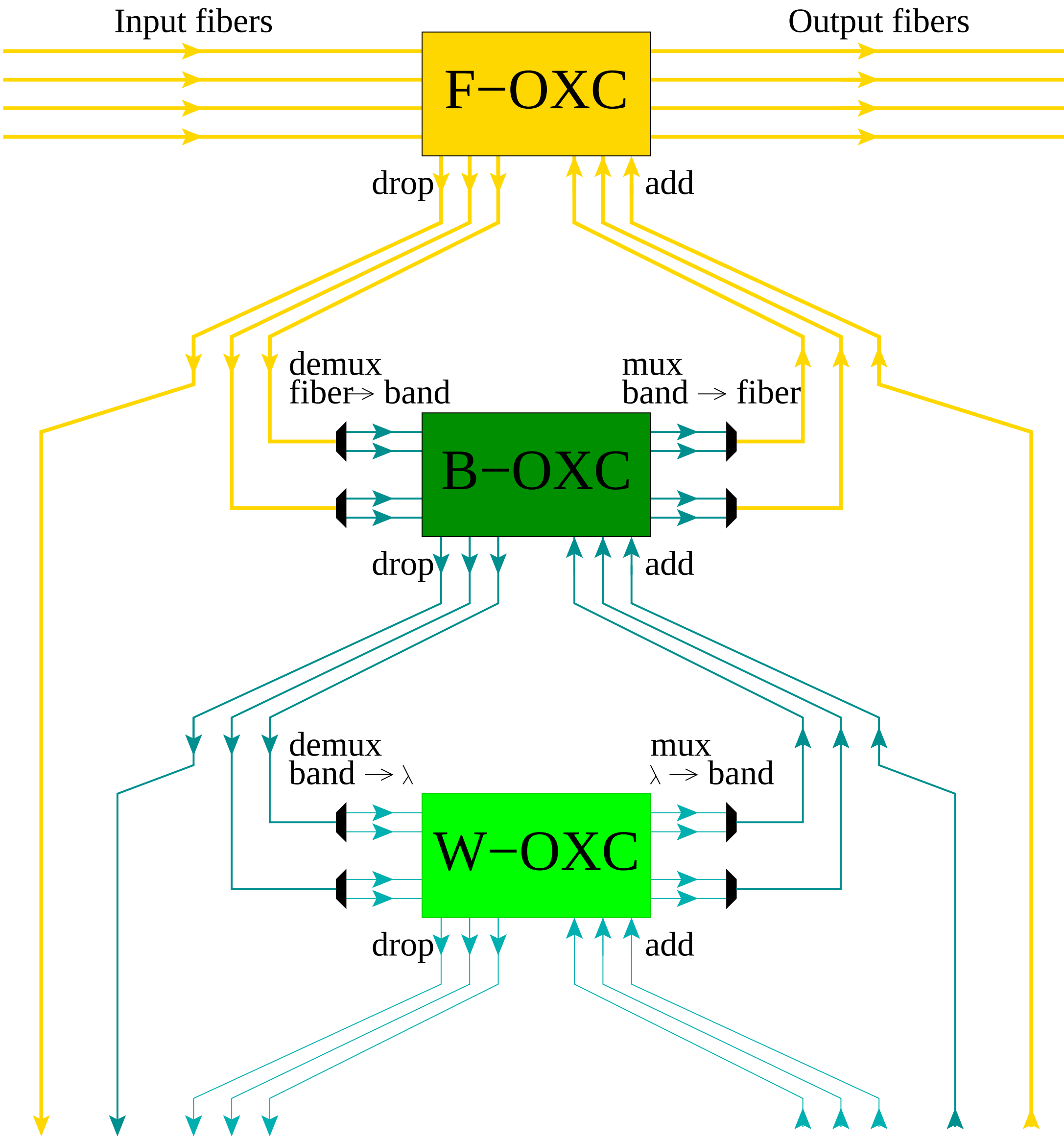
References

- Dutta & Rouskas, *Traffic grooming in WDM Networks : past and future*, IEEE Network, 16(6) 2002
- Modiano & Lin, *Traffic grooming in WDM Networks*, IEEE Communications magazine, 39(7) 2001
- Huiban, Pérennes & Syska, IEEE ICC, 2002
- Bermond, Coudert & Muñoz, ONDM, Feb 2003
- Bermond & Céroi, Networks, 41, 2003
- Bermond & Coudert, IEEE ICC, May 2003
- Bermond, De Rivoyre, Pérennes & Syska, submitted to Algotel

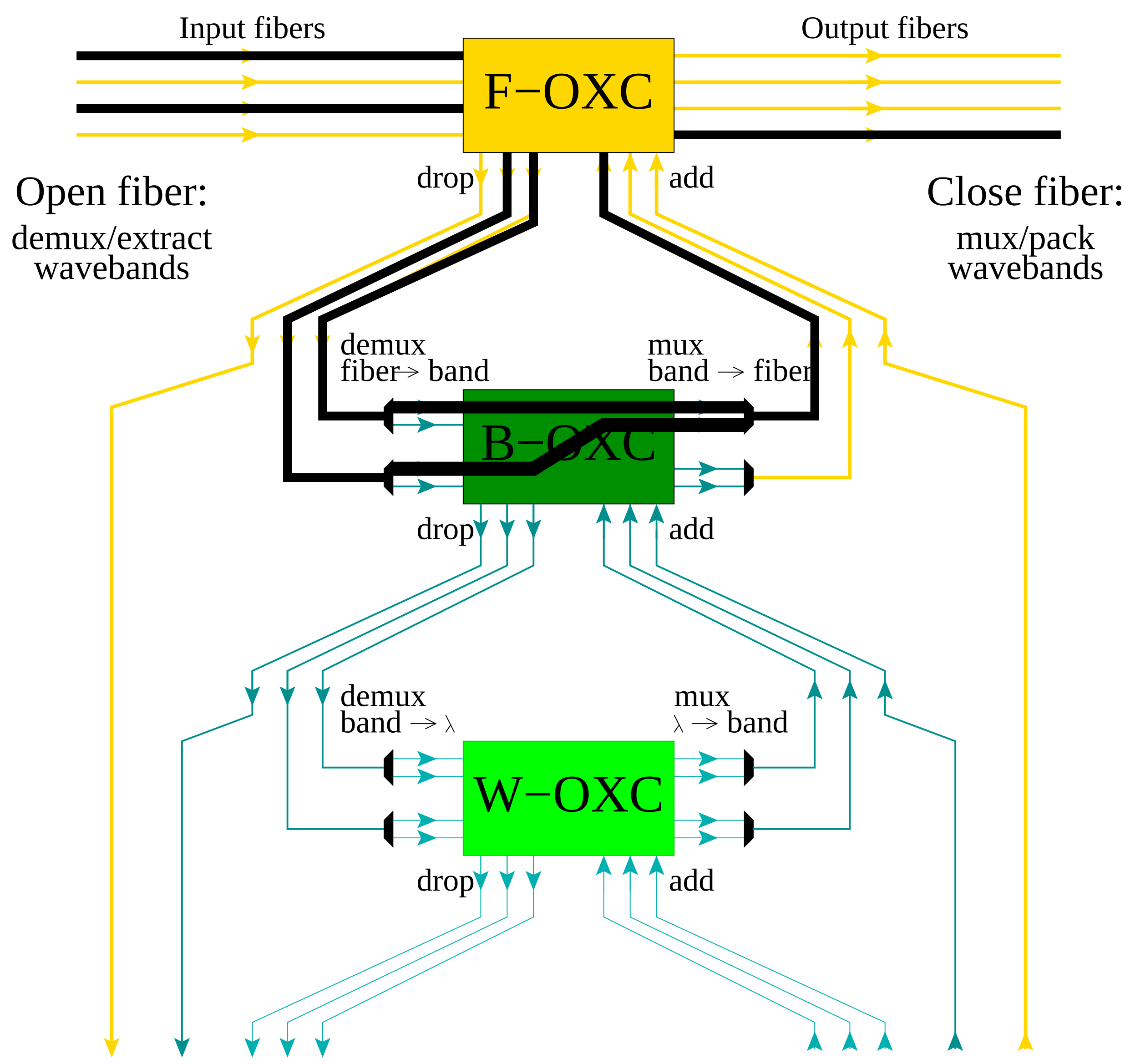
PORTO

- PORTO RNRT project with France Telecom R&D and Alcatel
- PORTO = “Planification et optimisation de réseaux de transport optique”
- group wawelengths into bands (example 8 wawelengths per band)
- group bands into fibers (example 4 bands per fiber)

A node (project PORTO)

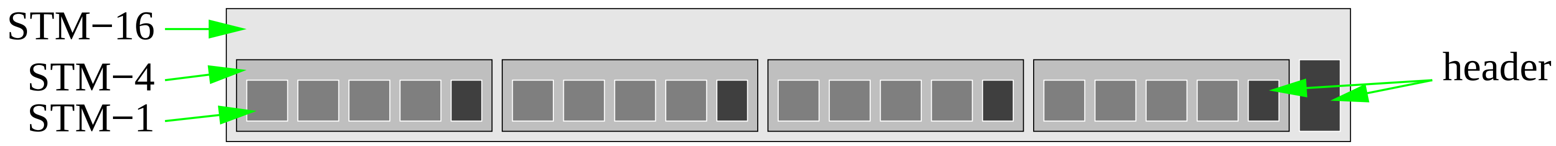


Opening a Fiber



SONET/SDH

- SONET = Synchronous Optical NETwork (USA)
- SDH = Synchronous Digital Hierarchy (Europe)
  - STM = Synchronous Transfert Module



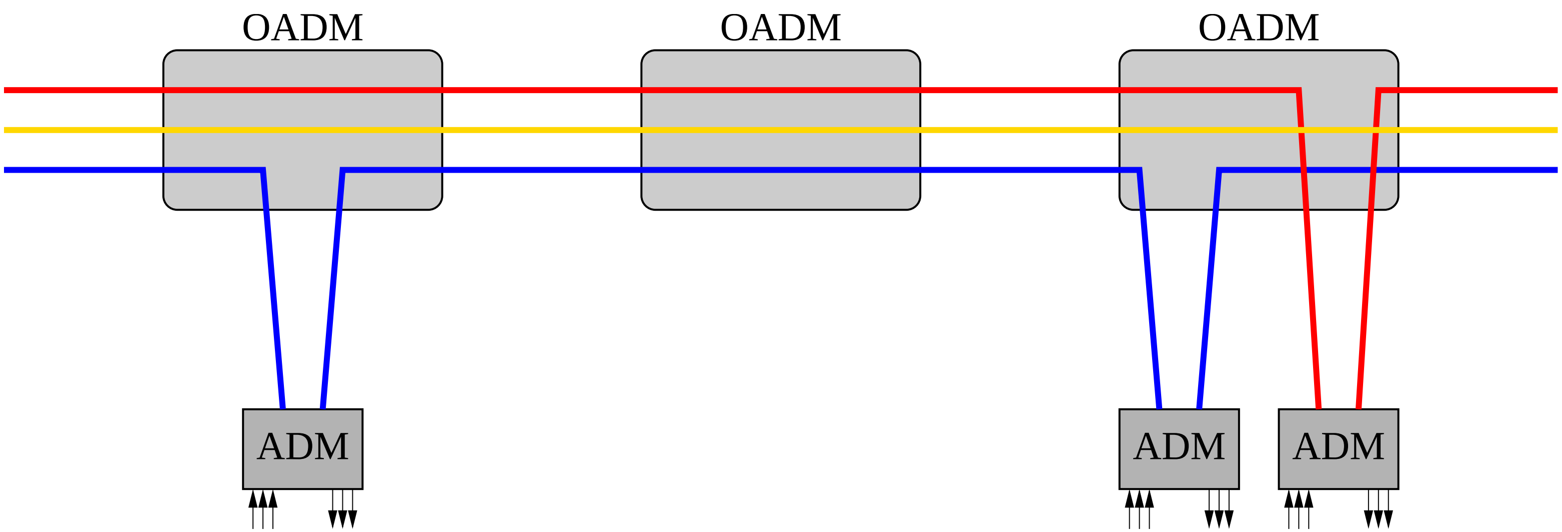
- Aggregate low rate traffic streams on one wavelength

SONET/SDH

SONET	OC 1	OC 3	OC 4	OC 12	OC 16
SDH		STM-1		STM-4	
Bandwidth	52 Mb/s	155 Mb/s	$\sim$ 255 Mb/s	655 Mb/s	$\sim$ 1 Gb/s

SONET	OC 48	OC 64	OC 192	OC 768
SDH	STM-16		STM-64	STM-256
Bandwidth	2.5 Gb/s	$\sim$ 4 Gb/s	10 Gb/s	40 Gb/s

ADM & OADM

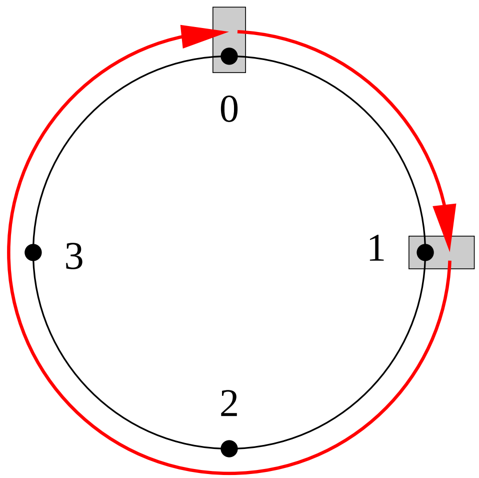


- **Idea:** Use ADM only at initial and terminal nodes of requests (lightpaths)

Without grooming

- $G = \overrightarrow{C}_4$
- All-to-all communications
  - All the couples of requests

(0,1) (1,0)
(1,2) (2,1)
(2,3) (3,2)
(3,0) (0,3)
(0,2) (2,0)
(1,3) (3,1)



- 12 requests $\Rightarrow$ 6 wavelengths and 12 ADMs

With grooming

- Grooming factor $C = 3$
- All-to-all communications
  - All the couples of requests

(0,1) (1,0)
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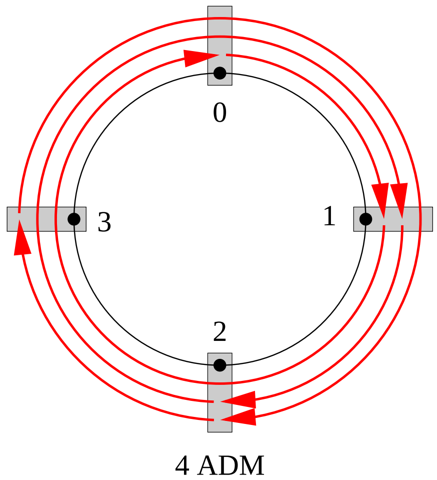

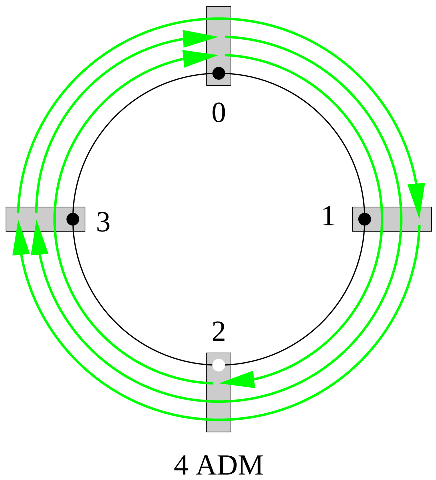

- 2 wavelengths and 8 ADMs

With grooming (2)

- Grooming factor $C = 3$
- All-to-all communications
  - All the couples of requests

(0,1) (1,0)
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(3,0) (0,3)
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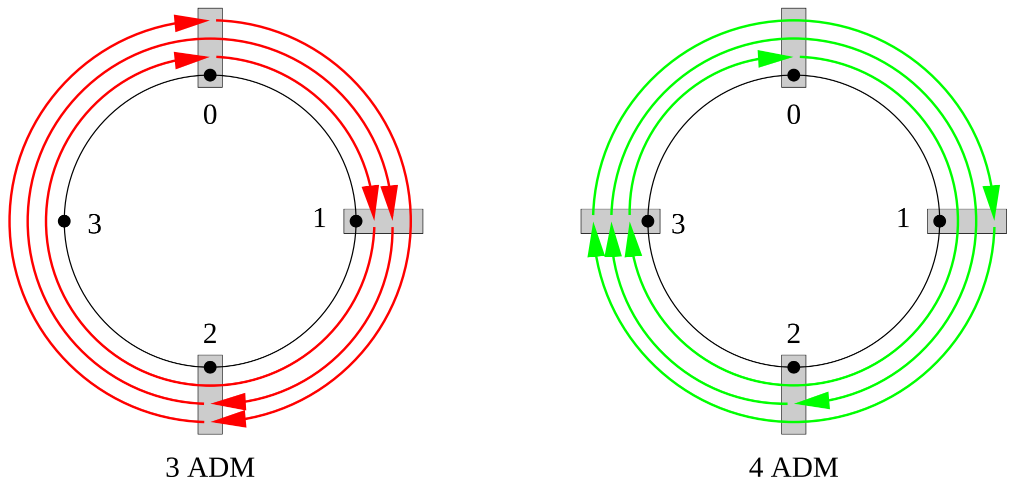

- 2 wavelengths and 7 ADMs

Grooming / Routing / Protection

- Focus on grooming
- But other important problems to be considered
  - Routing and allocation, RWA
  - Protection

- We consider unidirectional rings
  - Unique routing
  - Protection ensured by an opposite ring
  - Requests (A, B) and (B, A) use the same wavelength
    $\Rightarrow$ undirected requests graph

Grooming problem

- Inputs
  - Unidirectional SONET/WDM ring with N nodes
  - Set of symmetric requests, I 1 request = 1 STM
  - Grooming factor, C 1 wavelength = C STM
    (1 request use $1/C$ of the bandwidth of the wavelength)
- Outputs
  - Aggregation of STM into wavelengths
- Goal:
  - Minimize the total number of ADMs

Modelization

- All-to-all unitary case: $I = K_N$
- 1 wavelength = 1 graph $G_i = (V_i, E_i)$, such that $|E_i| \leq C$.
  - An edge of G_i = 1 request
  - A node of G_i = 1 ADM

Inputs	complete graph K_N and grooming factor C
Outputs	Subgraphs $G_i = (V_i, E_i)$
	such that $|E_i| \leq C$ and $\cup_i E_i = E$
Objectif	Minimize $\sum_i |V_i|$

With grooming

- Grooming factor $C = 3$
- All-to-all communications
  - All the couples of requests

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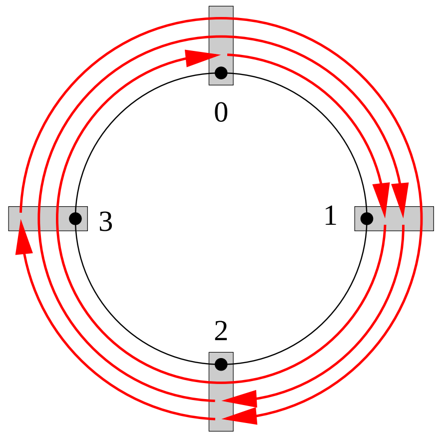
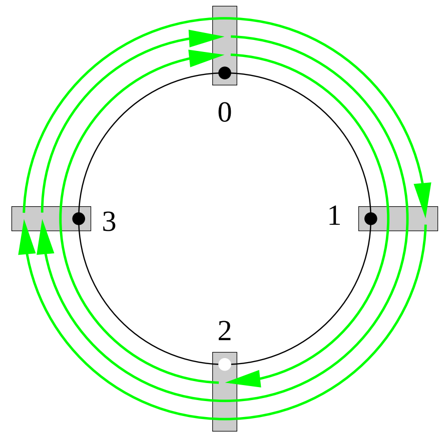


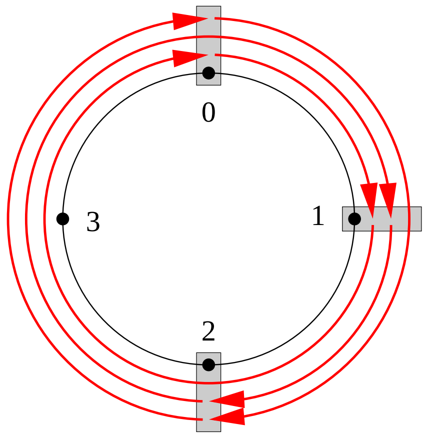


- 2 wavelengths and 8 ADMs

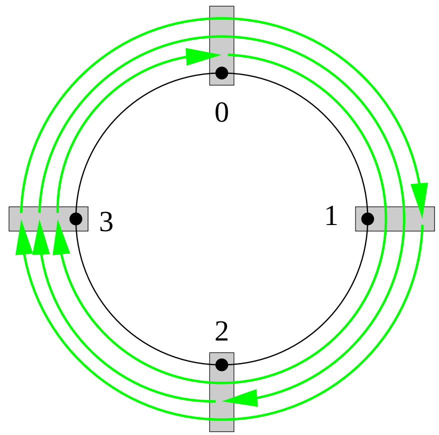
With grooming (2)

- Grooming factor $C = 3$
- All-to-all communications
  - All the couples of requests

(0,1) (1,0)
(1,2) (2,1)
(2,3) (3,2)
(3,0) (0,3)
(0,2) (2,0)
(1,3) (3,1)



3 ADM

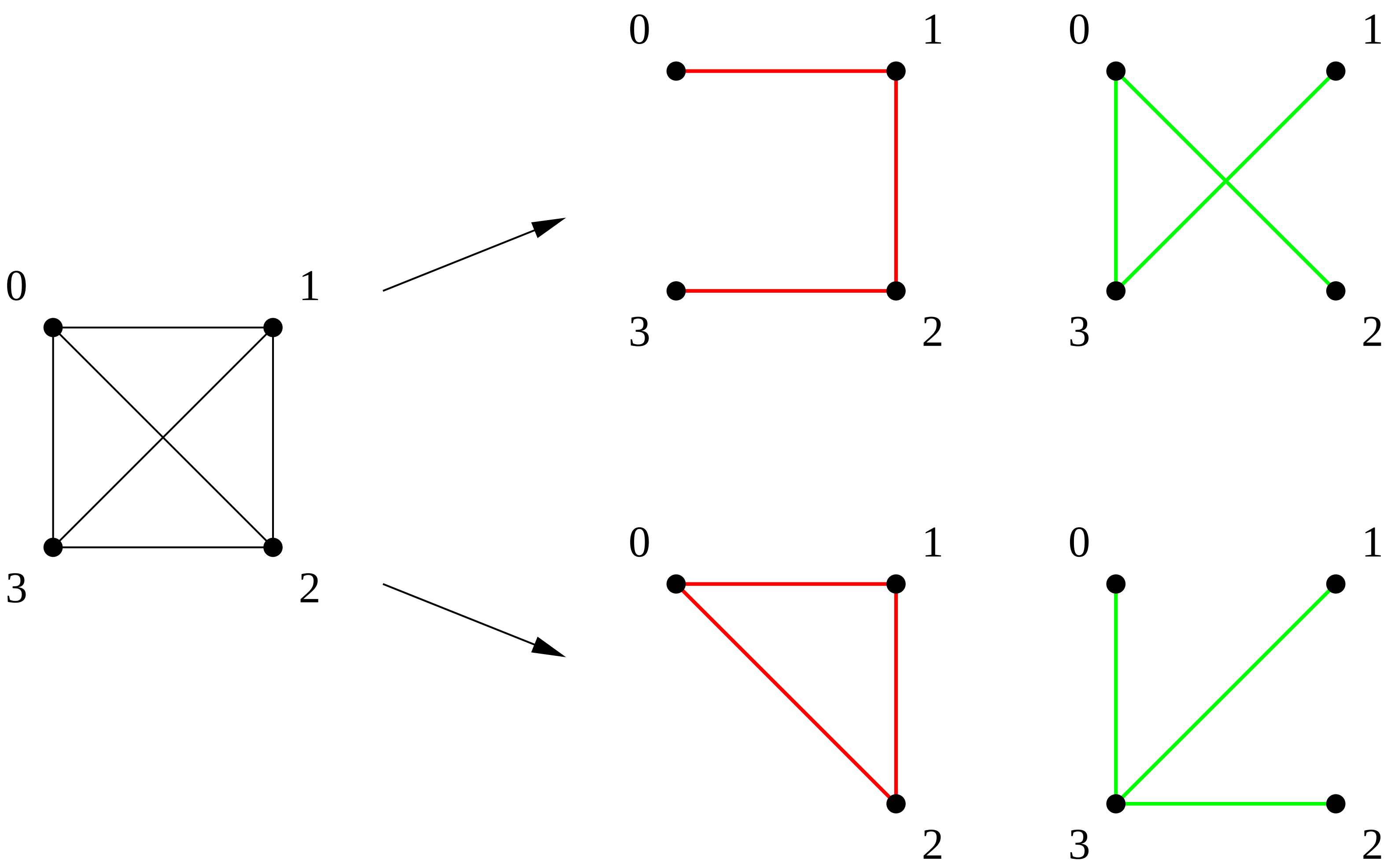


4 ADM

- 2 wavelengths and 7 ADMs

Example

- $N = 4$ and $C = 3$



Objective

- Minimization of the number of wavelengths
  = put C requests per wavelength
- Minimization of the number of ADMs
  = find subgraphs G_i with $|E_i| \leq C$ such that $\frac{|E_i|}{|V_i|}$ is maximized

Objective

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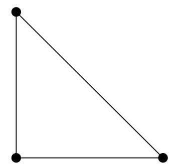
- For general instance I it was known that the objectives are different
- **Conjecture (Chiu & Modiano):** For All-to-All, the minimum number of ADMs can be obtained using the minimum number of wavelengths

[DISPROVED]

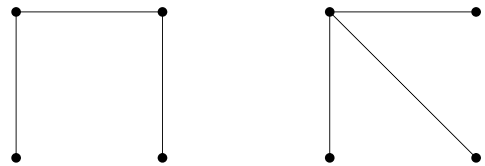
Example

$C = 3$



3 requests

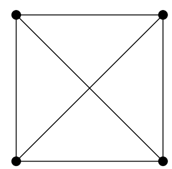
3 ADMs



3 requests

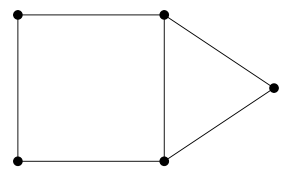
4 ADMs

$C = 6$



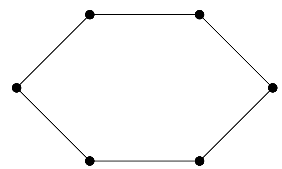
6 requests

4 ADMs



6 requests

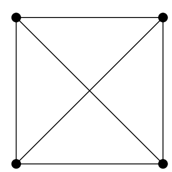
5 ADMs



6 requests

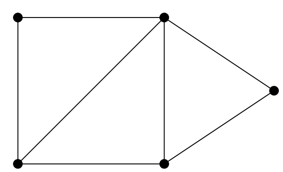
6 ADMs

$C = 7$



6 requests

4 ADMs



7 requests

5 ADMs

ratio $\frac{6}{4} = 1.5$ $\frac{7}{5} = 1.4$

Lower bound

- $\rho_{\max}(C) = \max_{m \leq C}\{$ ratio of graphs with m edges $\}$
- **Theorem:** $A(C, N) \geq \frac{N(N-1)}{2\rho_{\max}(C)}$

Lower bound

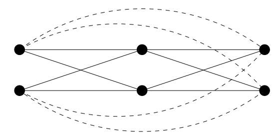
- $\rho_{\max}(C) = \max_{m \le C}\{$ ratio of graphs with m edges $\}$
- **Theorem:** $A(C,N) \ge \frac{N(N-1)}{2\rho_{\max}(C)}$
- From Design Theory : G-Design of order N
  = partition the edges of K_N into subgraphs isomorphic to G
- **Theorem:** Given C, for an infinite number of values of N, $A(C,N) = \frac{N(N-1)}{2\rho_{\max}(C)}$.

Lower bound

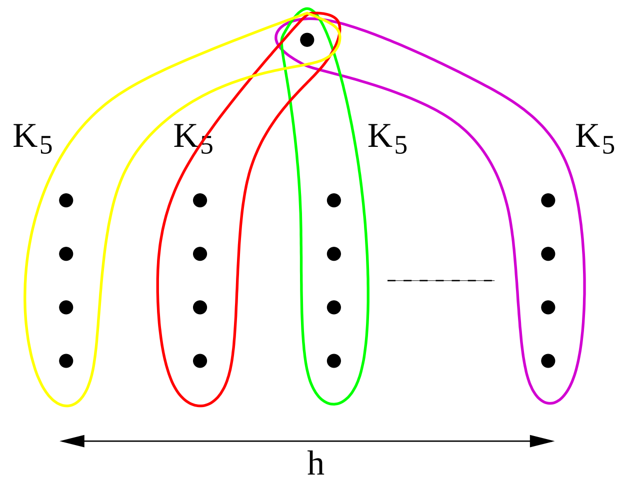
- $\rho_{\max}(C) = \max_{m \leq C}\{$ ratio of graphs with m edges $\}$
- **Theorem:** $A(C,N) \geq \frac{N(N-1)}{2\rho_{\max}(C)}$
- From Design Theory : G-Design of order N
  = partition the edges of K_N into subgraphs isomorphic to G
- **Theorem:** Given C, for an infinite number of values of N,
  $A(C,N) = \frac{N(N-1)}{2\rho_{\max}(C)}$.
  - $A(3,N) = \frac{N(N-1)}{2}$ when $N \equiv 1, 3 \pmod 6$ K_3
  - $A(6,N) = A(7,N) = \frac{N(N-1)}{3}$ when $N \equiv 1, 4 \pmod{12}$ K_4
  - $A(16,N) = A(15,N) = \frac{N(N-1)}{5}$ when $N \equiv 1 \pmod{30}$ K_6

Example C=12

- Optimal graphs: K_5 and $K_{2,2,2}$



- **Theorem:** If $N = 4h + 1$, $A(12, 4h + 1) = h(4h + 1)$
- **Proof:**



  - $K_{4h+1} \longrightarrow hK_5 + K_{\underbrace{4,4,\ldots,4}_{\text{h times}}}$
  - $h \equiv 0$ or $1 \pmod 3$
    - $K_{2,2,\ldots,2} \longrightarrow K_3$
    - replacing each vertex by 2 vertices

      $\Rightarrow K_{4,4,\ldots,4} \longrightarrow K_{2,2,2}$
  - $h \equiv 0 \pmod 3$ use a $K_{4,4,\ldots,4,8}$

Summarize of existing results

- Small cases: $N \leq 16$ and $C = 3, 4, 12, 16, 48, 64$
  - Exemple: $C = 48$, $N = 16$, $A = 32$, before $29 \leq A \leq 34$
- $C = 3$ for all N [Bermond & Ceroi, *Networks 03*]
- $C = 4$ for all N [Hu, *OSA JON 02*]
- $C = 5$ for all N [Bermond, Colbourn, Ling & Yu, *submitted*]
- $C = 12$ and $N = 4h + 1$
- $C \geq \frac{N(N-1)}{6}$ for all N
- $\frac{k(k-1)}{2} \leq C \leq \frac{(k+1)(k-1)}{2}$ and $\begin{cases} \frac{N(N-1)}{2} \equiv 0 \mod \frac{k(k-1)}{2} \\ N-1 \equiv 0 \mod k-1 \end{cases}$
  - Partition of K_N into K_k

Perspectives

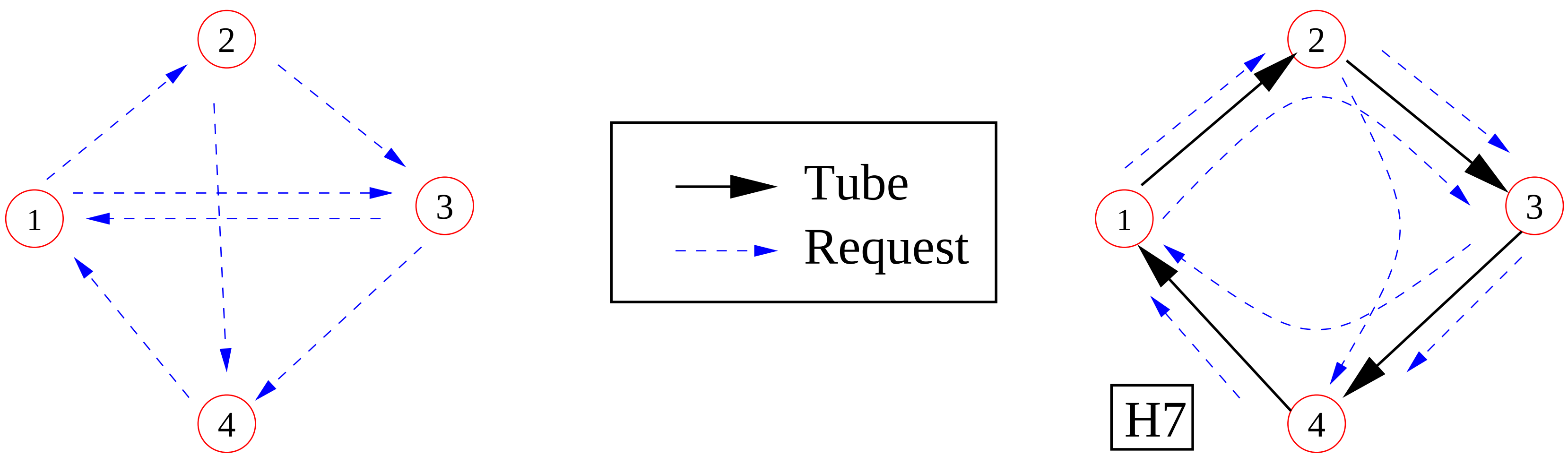
- General set of requests
  - $\sim \sqrt{C}$-approximation [Goldschmidt, Hochbaum, Levin & Olinick, *Networks 03*]
- Other topologies
  - Bidirectionnal ring
    - $C = 8$ [Colbourn & Ling, *Discrete Math 03*]
  - Tree of rings

Another problem

- Group REQUESTS (low speed components) into higher ones called PIPES.
- Here a request is routed via several pipes.
- **Objective:** Minimize the total number of pipes (only specific equipments like ADMs at the end of the pipes).
- grooming factor C = maximum of requests using the same pipe
- **Remarks:**
  - Problem different from the VPL (Virtual Path Layout) design problem where pipes can contain as many requests as wanted.
  - Here we don't consider the routing problem associated and the load parameter of the physical links.

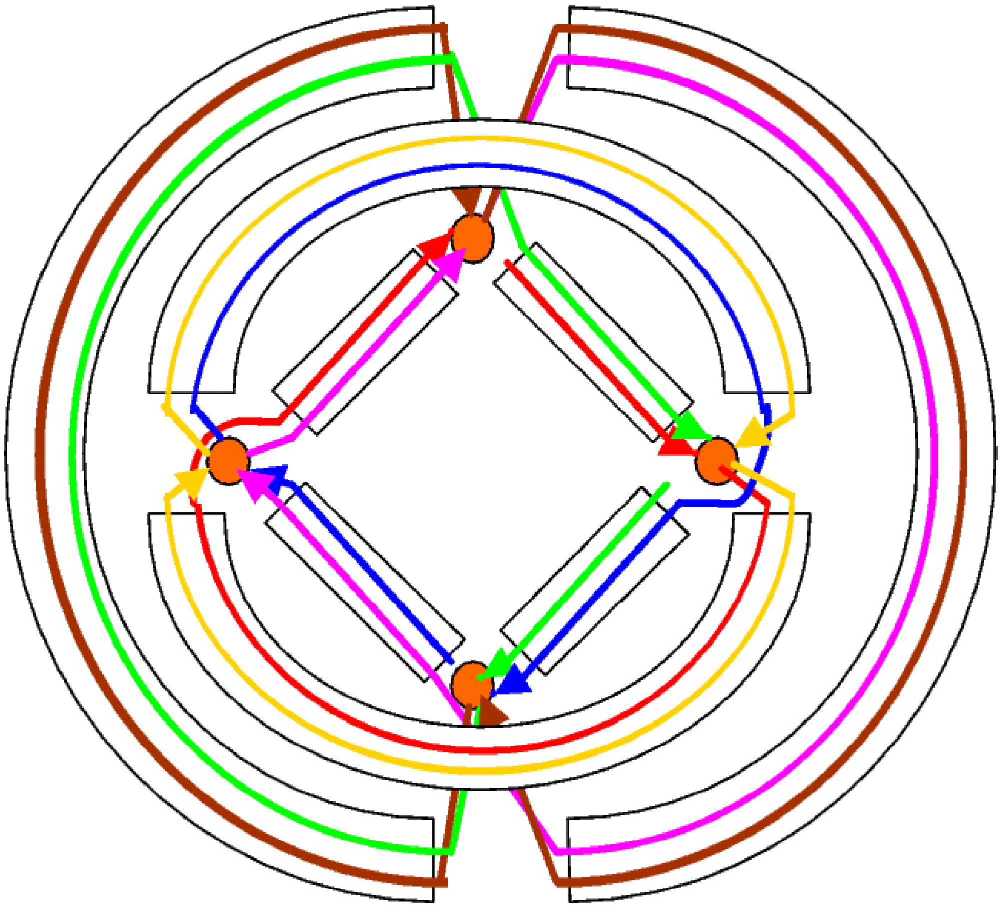
Grooming problem

- **Input :** traffic = set of directed requests = instance digraph
- **Output :** a virtual multidigraph H allowing the routing of the requests with at most C requests using one pipe
- **Objective :** Minimize the total number of pipes
- An example with 7 requests and C= 3 (4 pipes)



A second example

- I = All to All ; C=2 ; number of pipes : 8



Lower bound

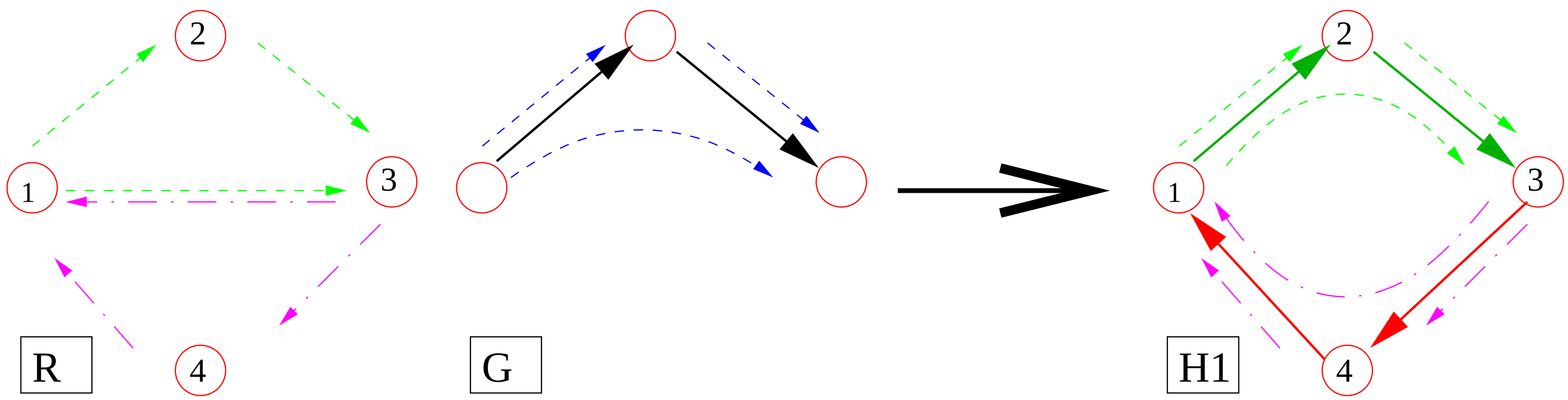
- **Theorem :** The number of pipes T for grooming a simple traffic (at most one request from s to d) with R requests and grooming factor C is at least $\frac{2R}{C+1}$
- **Proof :** Let R_i be the number of requests using i pipes $R = \sum_i R_i$ and $T \geq R_1$

$$\begin{aligned} C \cdot T &\geq \sum_i iR_i = 2R - R_1 + \sum_{i \geq 3}(i-2)R_i \\ &\geq 2R - T + \sum_{i \geq 3}(i-2)R_i \\ T &\geq \frac{2R + \sum_{i \geq 3}(i-2)R_i}{C+1} \geq \frac{2R}{C+1} \end{aligned}$$

- Lower bound attained if
  - all the pipes contain exactly C requests.
  - A request uses at most 2 pipes.
  - A pipe contains the request between its end nodes.

Constructions

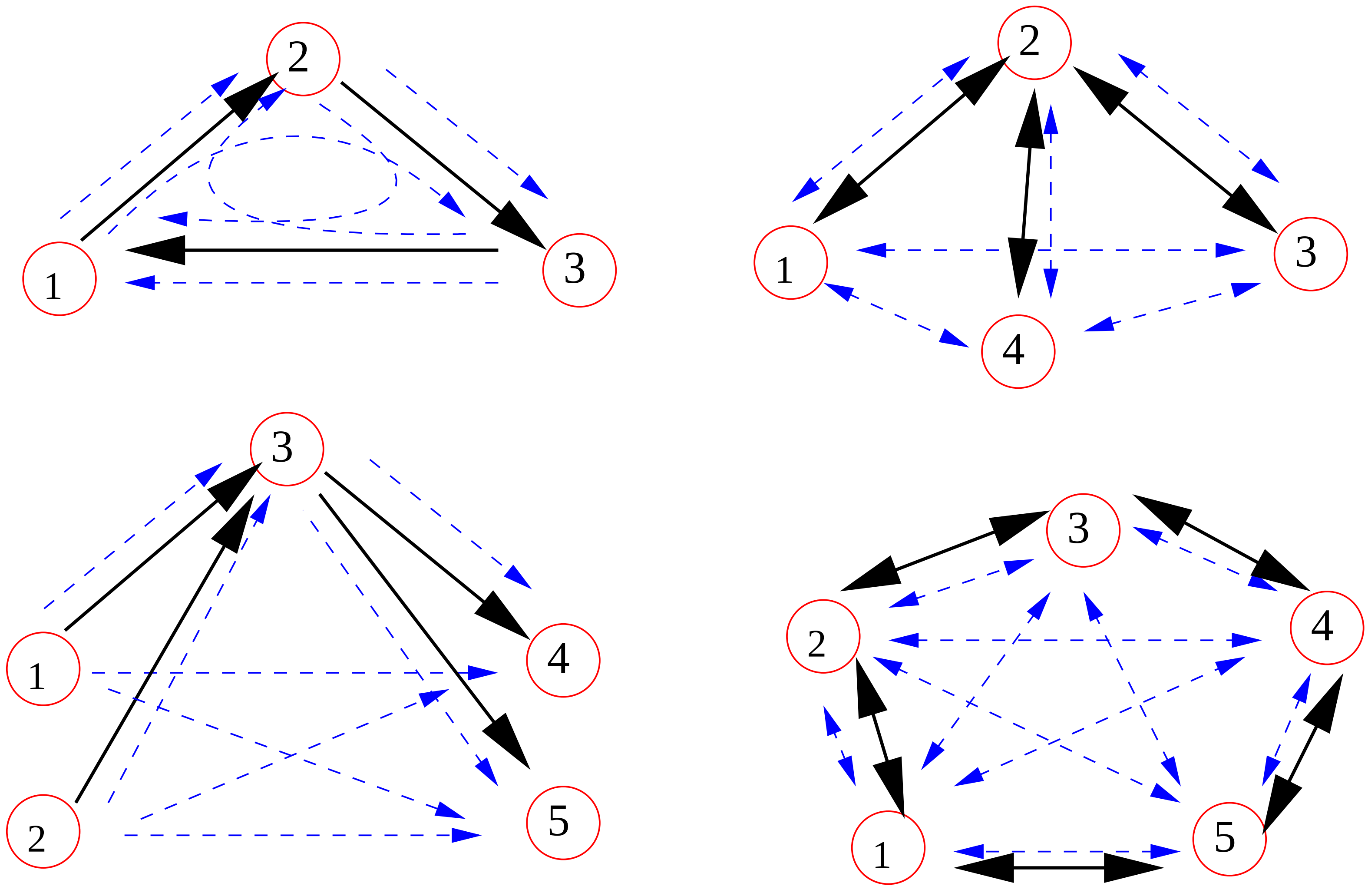
- Idea : Cover the set of requests I (arcs of I) into bricks
- Brick I_j has R_j requests which can be groomed with a minimum number of pipes $T_j = \frac{2R_j}{C+1}$.
- example for C=2 using as bricks transitive tournaments $TT3$



Results

- For $C = 2$ the grooming problem is NP-complete (reduction to the partition into triangles)
- For $C = 2$ et $n \neq 2 \mod [3]$, there exists a grooming with the minimum number of pipes ($T = \frac{2}{3}n(n-1)$) for I= All to All.
- For $C = 3$ and I = All to All, there exists a grooming with the minimum number of pipes $T = \frac{1}{2}n(n-1)$) for $n \notin \{6, 8\}$
- For general C fand I= All to All grooming with roughly $\frac{2R}{C}$ pipes

Bricks for C=3



Perspectives

- General instance I
  - Approximation algorithms for C= 2 ?
- Influence of the physical network
  - What is the minimum number of pipes if we have to embed them with a given load.
  - Case of the path, the unidirectional ring , etc ...
- More than two levels of grooming
  - Example SONET/SDH in wavelengths in bands in fibers.

Conclusion

- Merci de votre attention

Conclusion

- Merci de votre attention

Ce n’est qu’un début,

continuons le groupage !