

Tradeoffs in Cloud and Peer-assisted Content Delivery Systems

Niklas Carlsson
György Dan
Derek Eager
Anirban Mahanti

Linköping University
KTH Royal Institute of Technology
University of Saskatchewan
NICTA

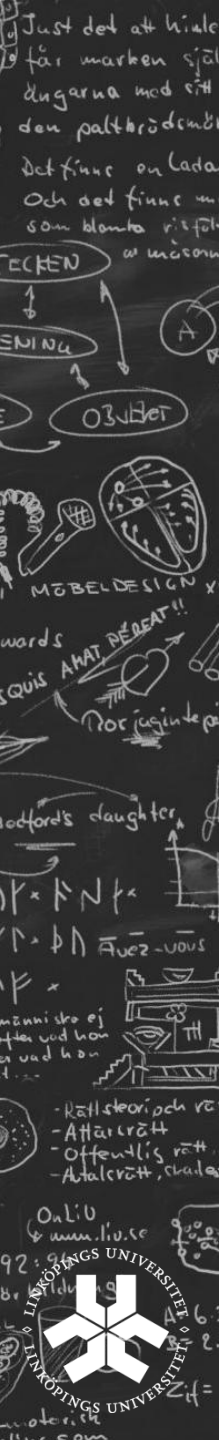


September 5, 2012

Motivation



- Content provider wanting to minimize its delivery cost
 - Catalogue of many contents
 - Different popularity
 - Average service guarantees



Motivation

- Cost-efficient solution must scale with regards to both:
 - Request rate
 - Number of available contents



Just det att kiale
får mariken själ
dugarna med sig
den paltbröden
Det finns en lada
Och det finns en
som blanda riktat
u mäsom

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MÖBELDESIGN

words
SQUIS AKAT DEBEAT!!
Por jaginte p

odford's daughter


DP x KN x
V x DN Avez-vous
PF x

männi sko ej
fter vad hon
en vad hon

- Rätt teori och r
- Attal rätt
- Offentlig rätt
- Attal rätt, skade

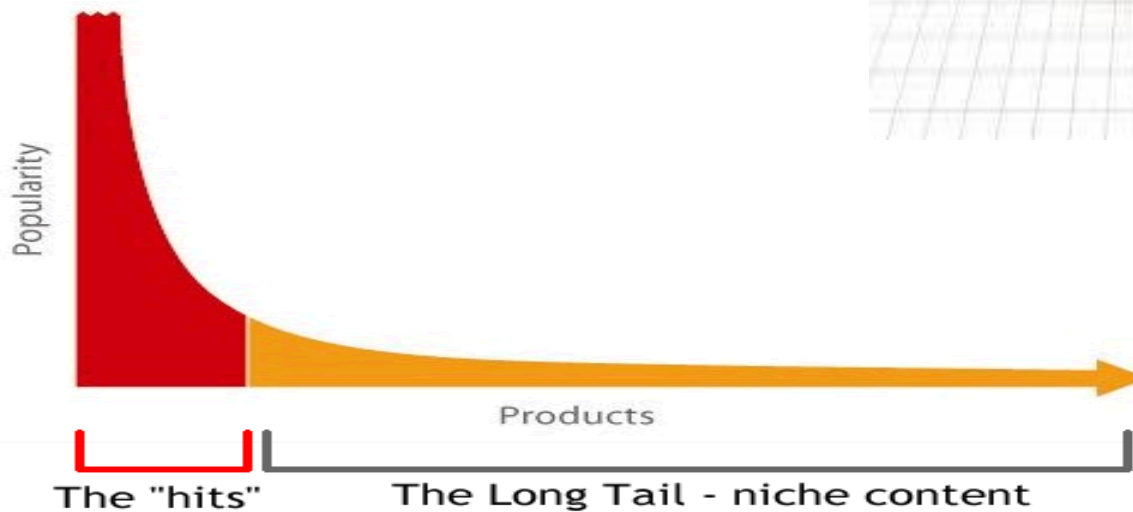
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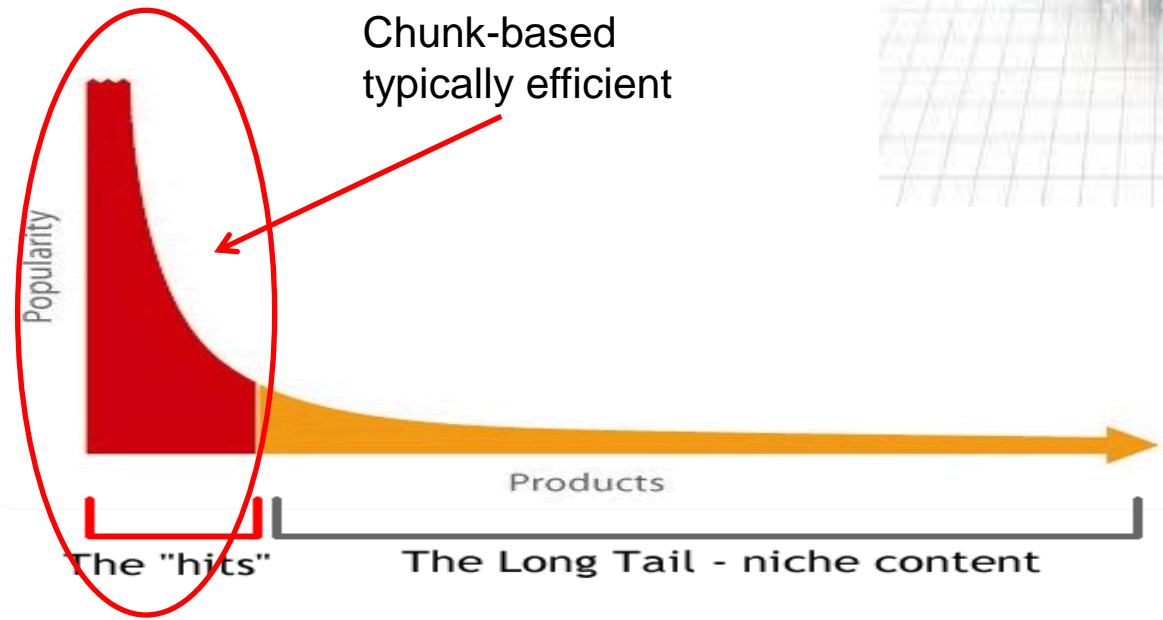
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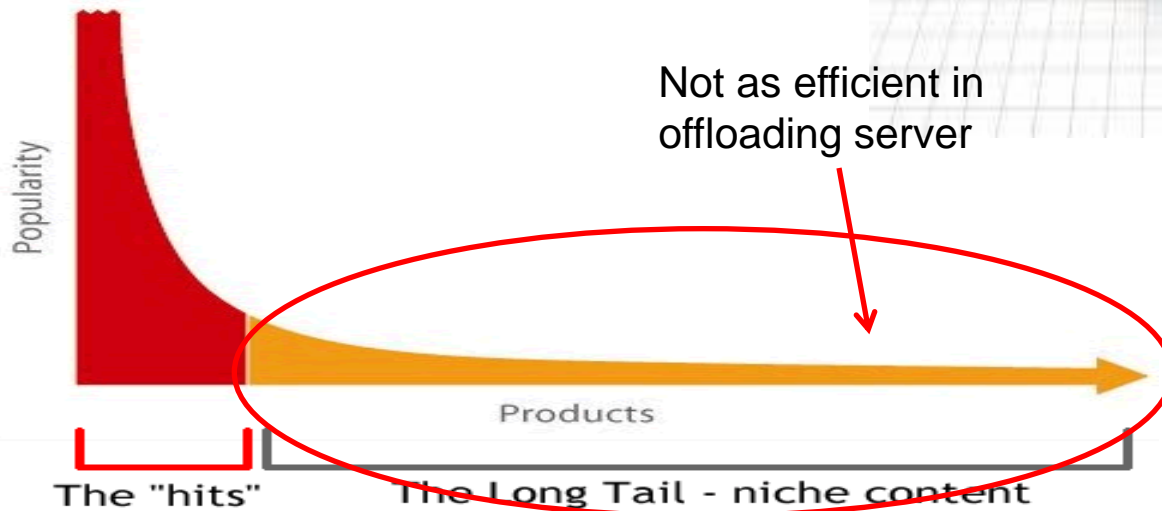
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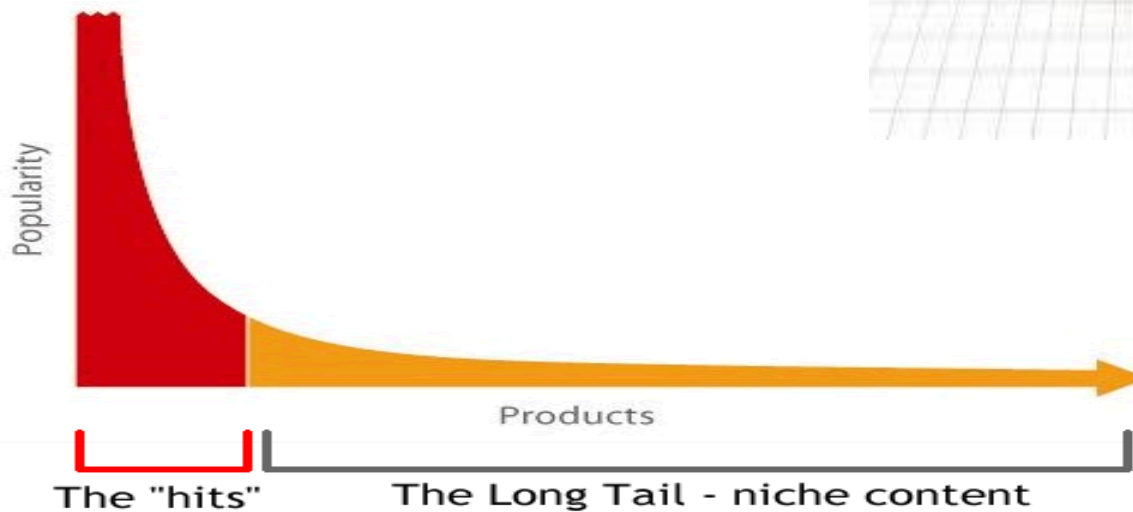
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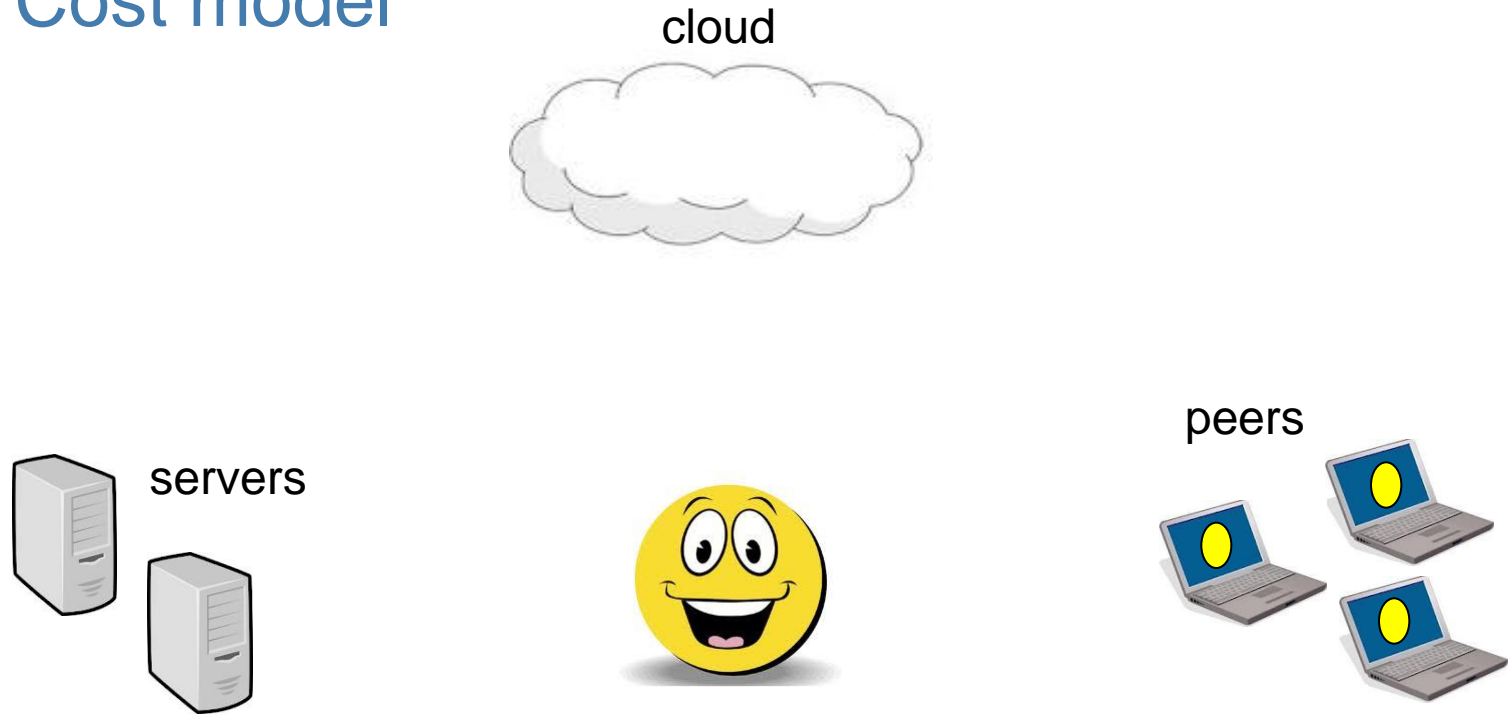
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Cost model



- Client can download from either
 - ❑ Origin servers (all contents)
 - ❑ Cloud storage/servers (subset of contents)
 - ❑ Other clients (peers)

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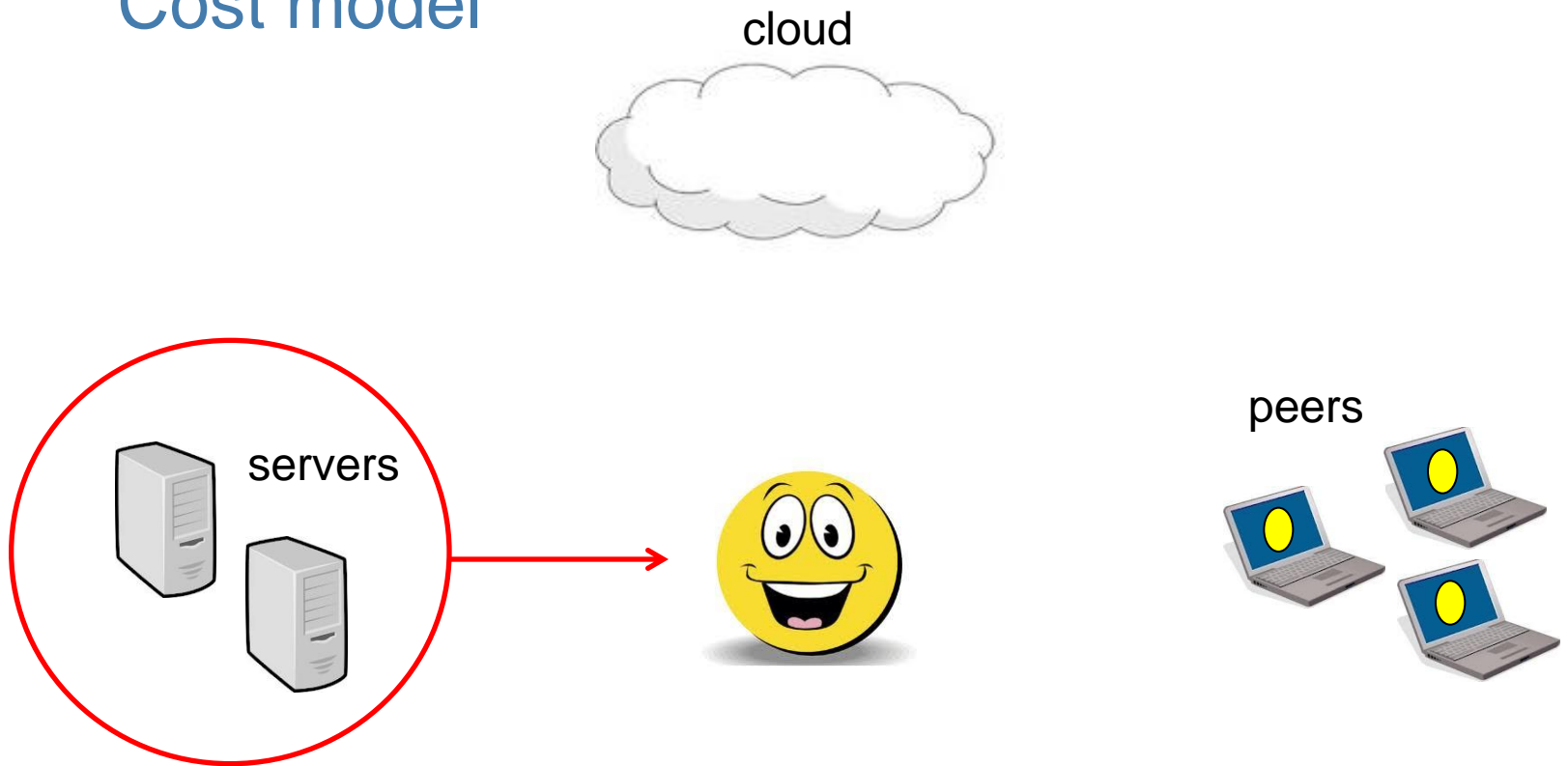
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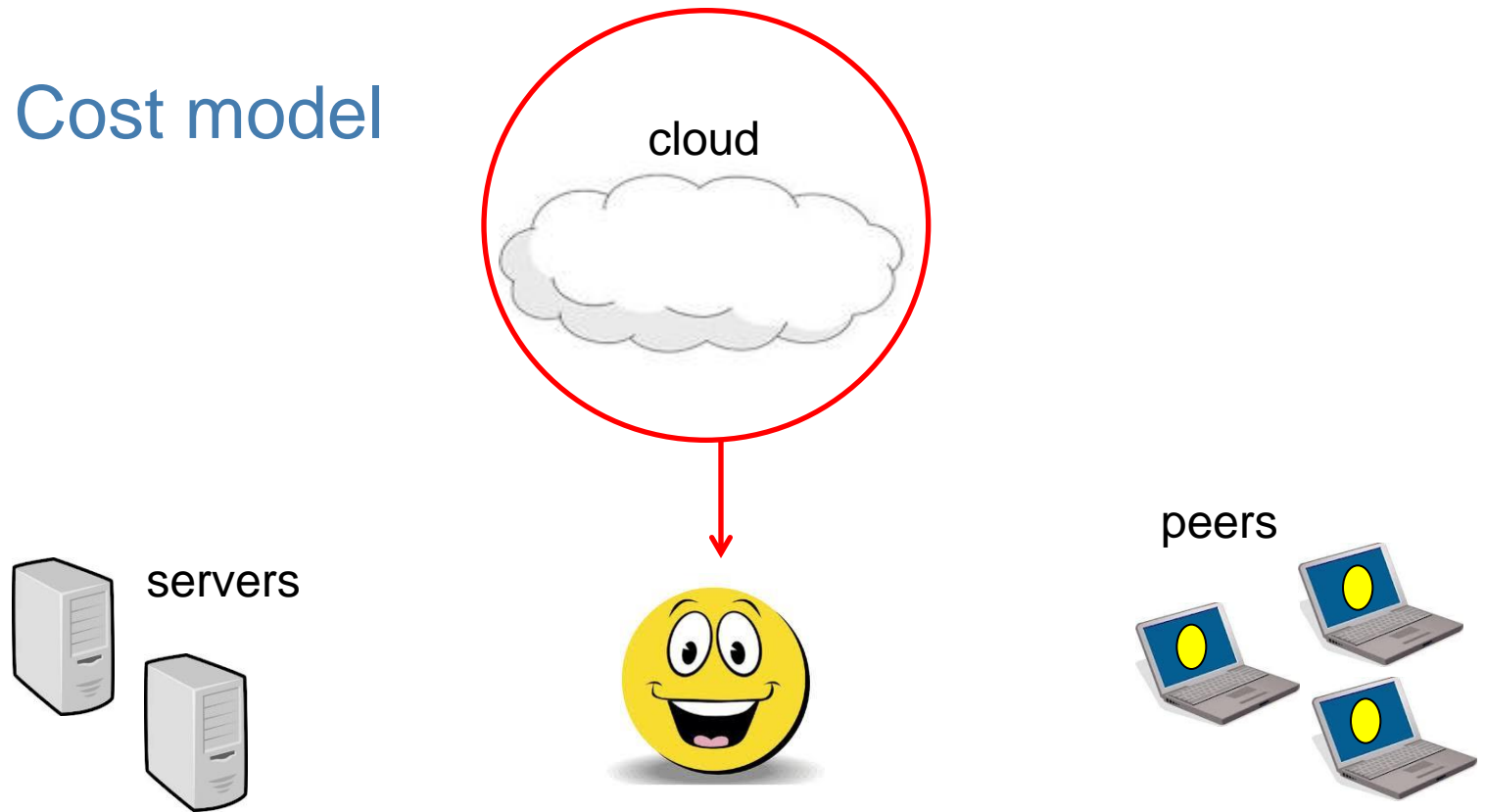
Cost model



- Client can download from either
 - ❑ **Origin servers (all contents)**
 - ❑ Cloud storage/servers (subset of contents)
 - ❑ Other clients (peers)



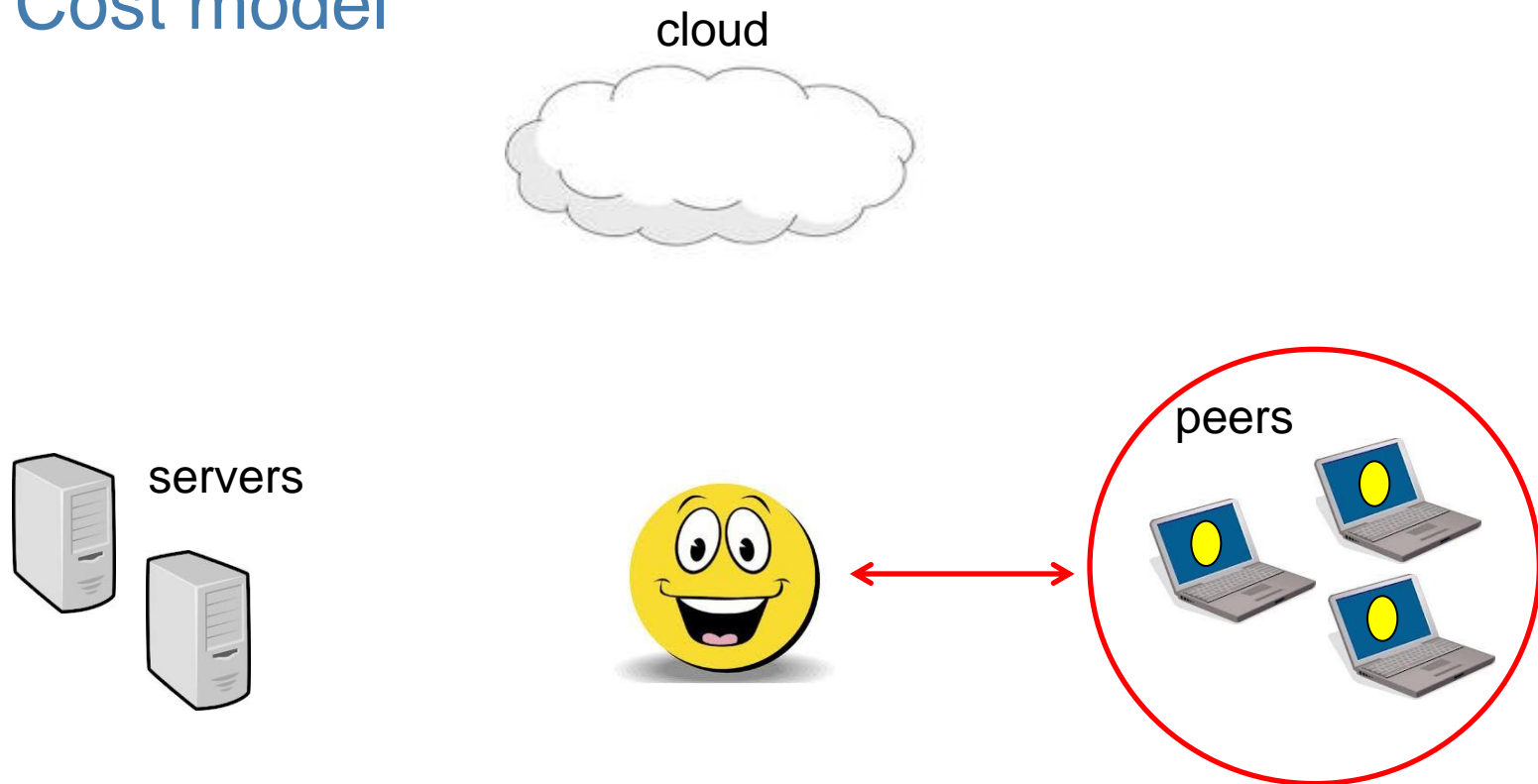
Cost model



- Client can download from either
 - ❑ Origin servers (all contents)
 - ❑ **Cloud storage/servers (subset of contents)**
 - ❑ Other clients (peers)



Cost model



- Client can download from either
 - ❑ Origin servers (all contents)
 - ❑ Cloud storage/servers (subset of contents)
 - ❑ **Other clients (peers)**

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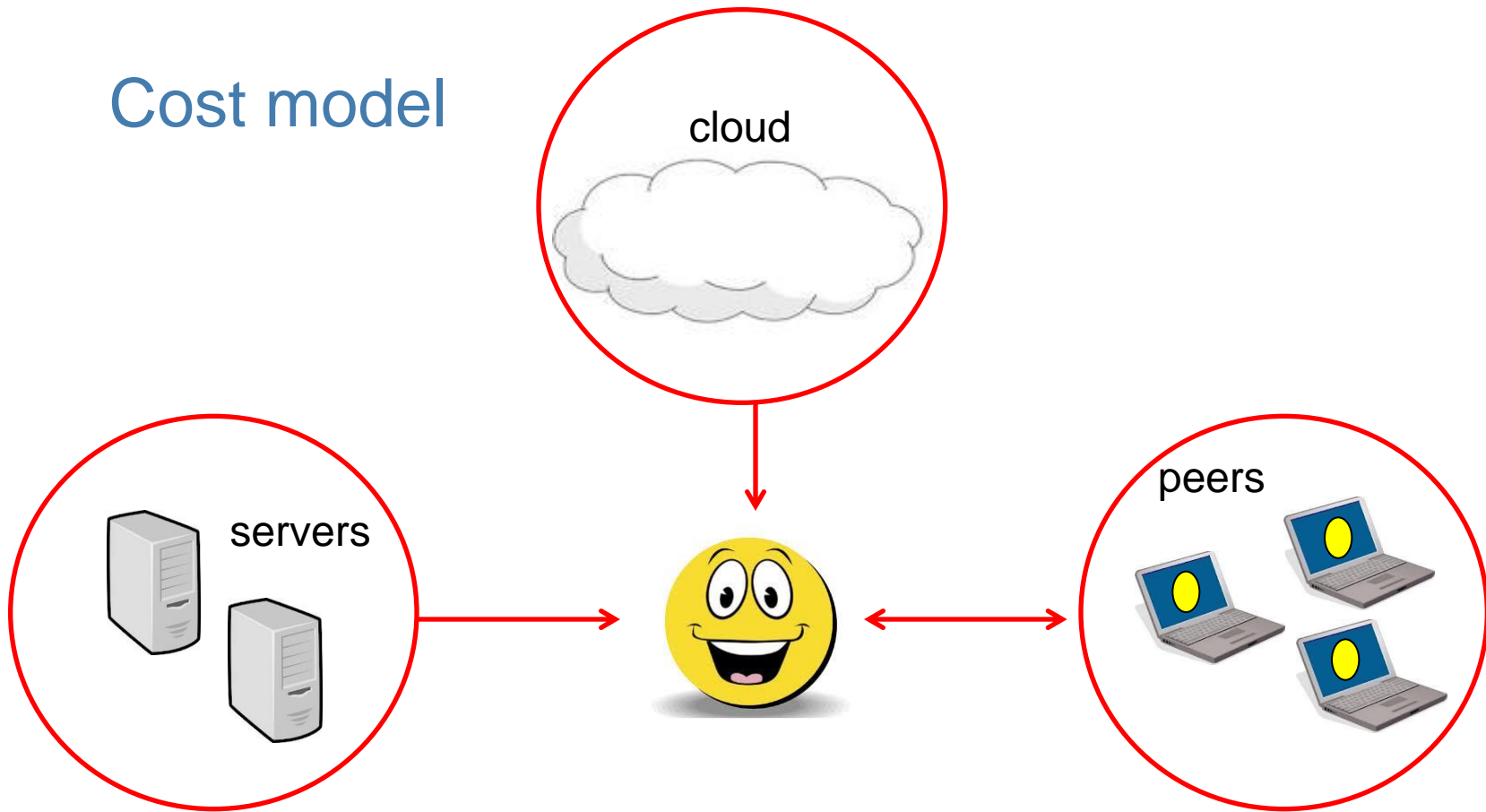
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Cost model



- Client can download from either
 - ❑ Origin servers (all contents)
 - ❑ Cloud storage/servers (some contents)
 - ❑ Other clients (peers)

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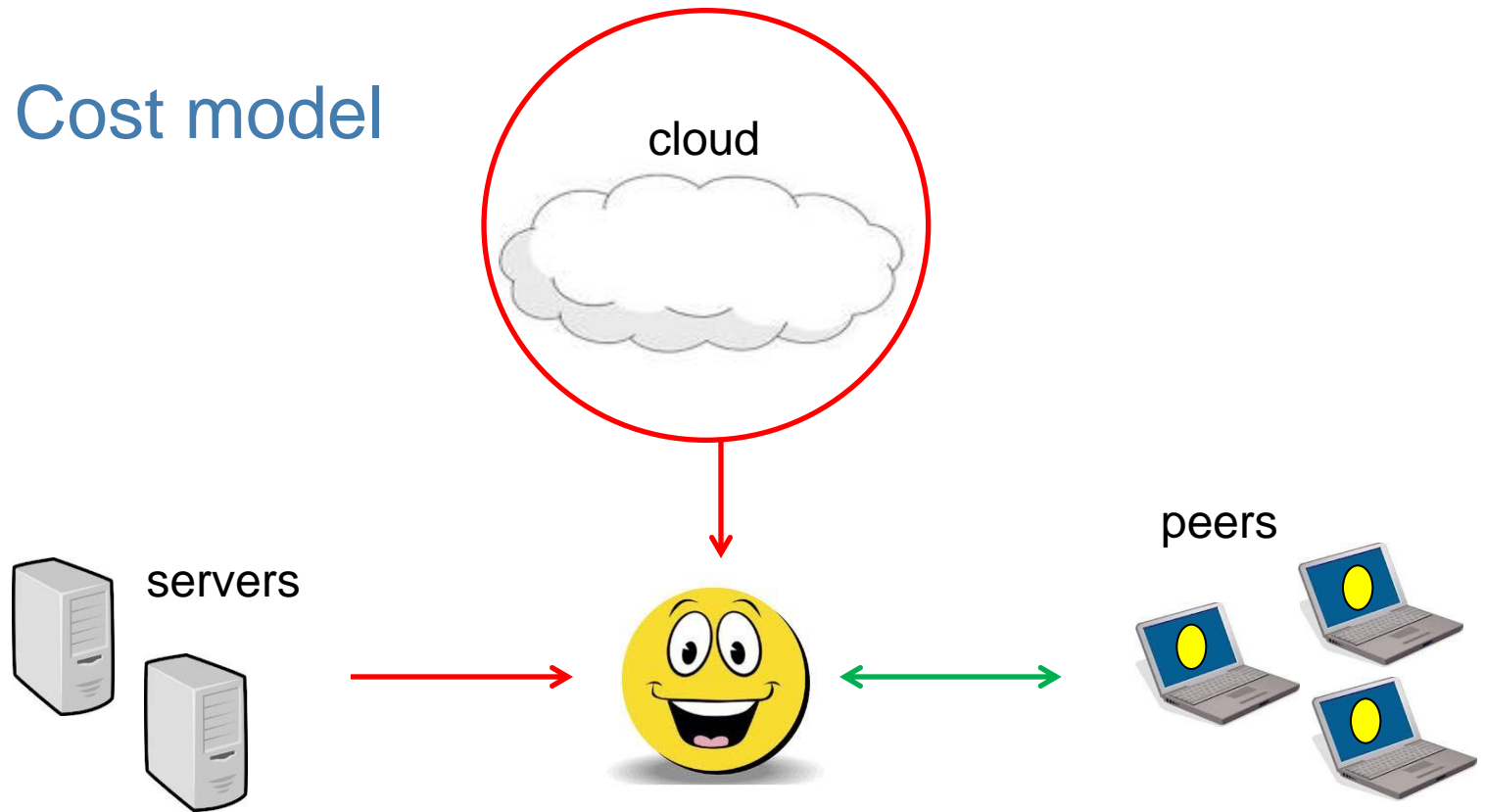
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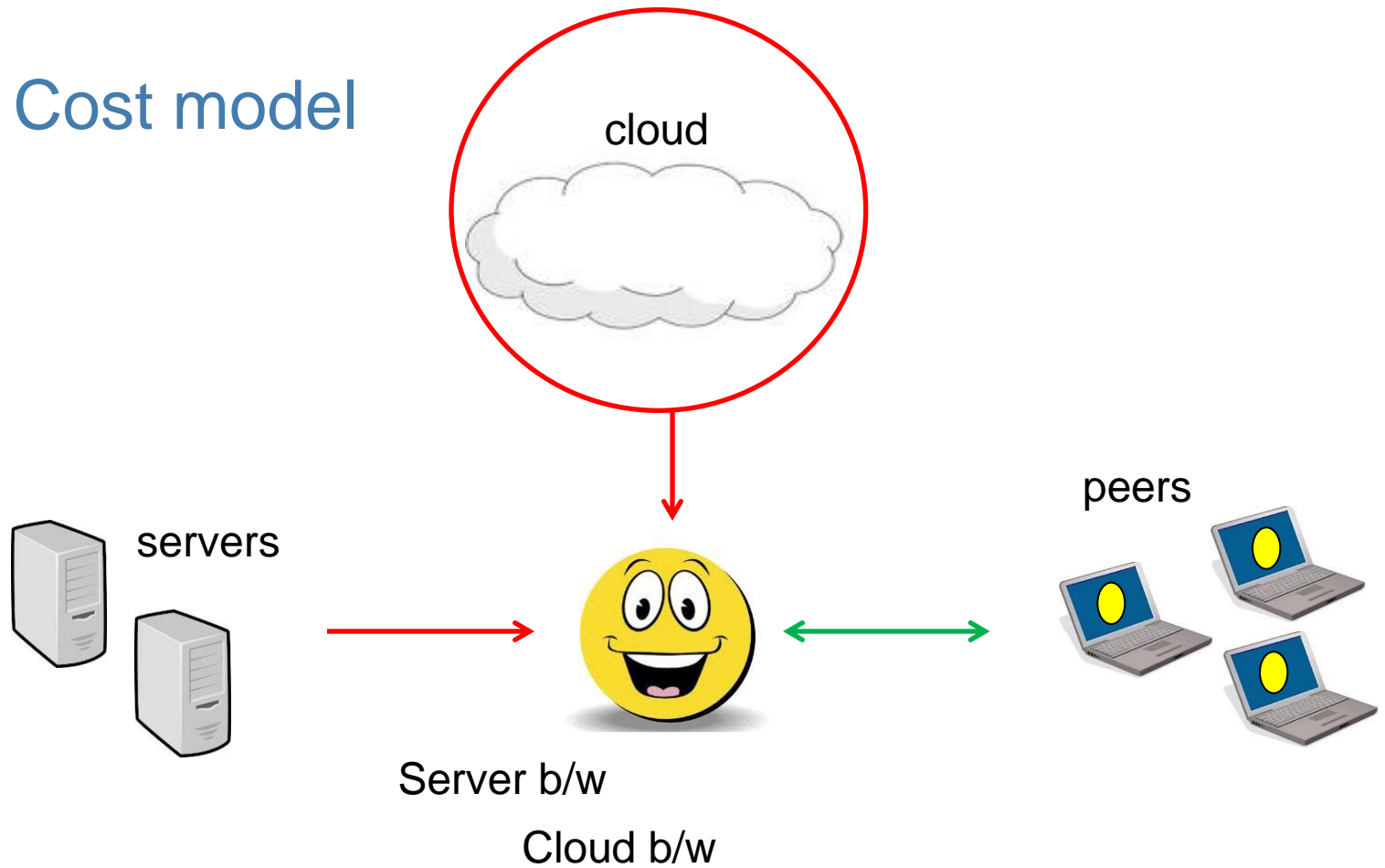
Cost model



- Client can download from either
 - ❑ Origin servers (all contents)
 - ❑ Cloud storage/servers (subset of contents)
 - ❑ Other clients (peers)



Cost model



- Simple cost model
 - Three (3) basic cost components

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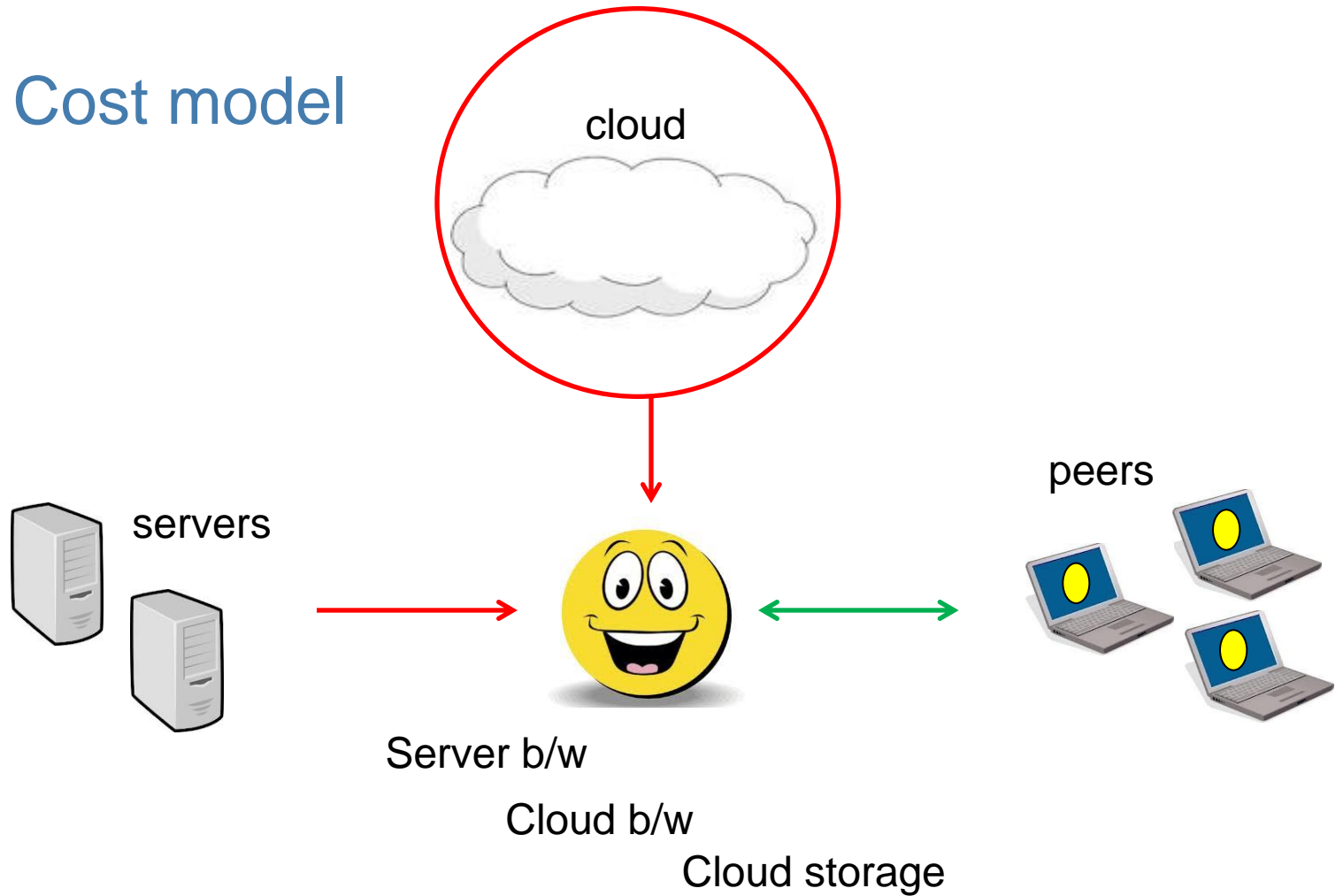
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Cost model



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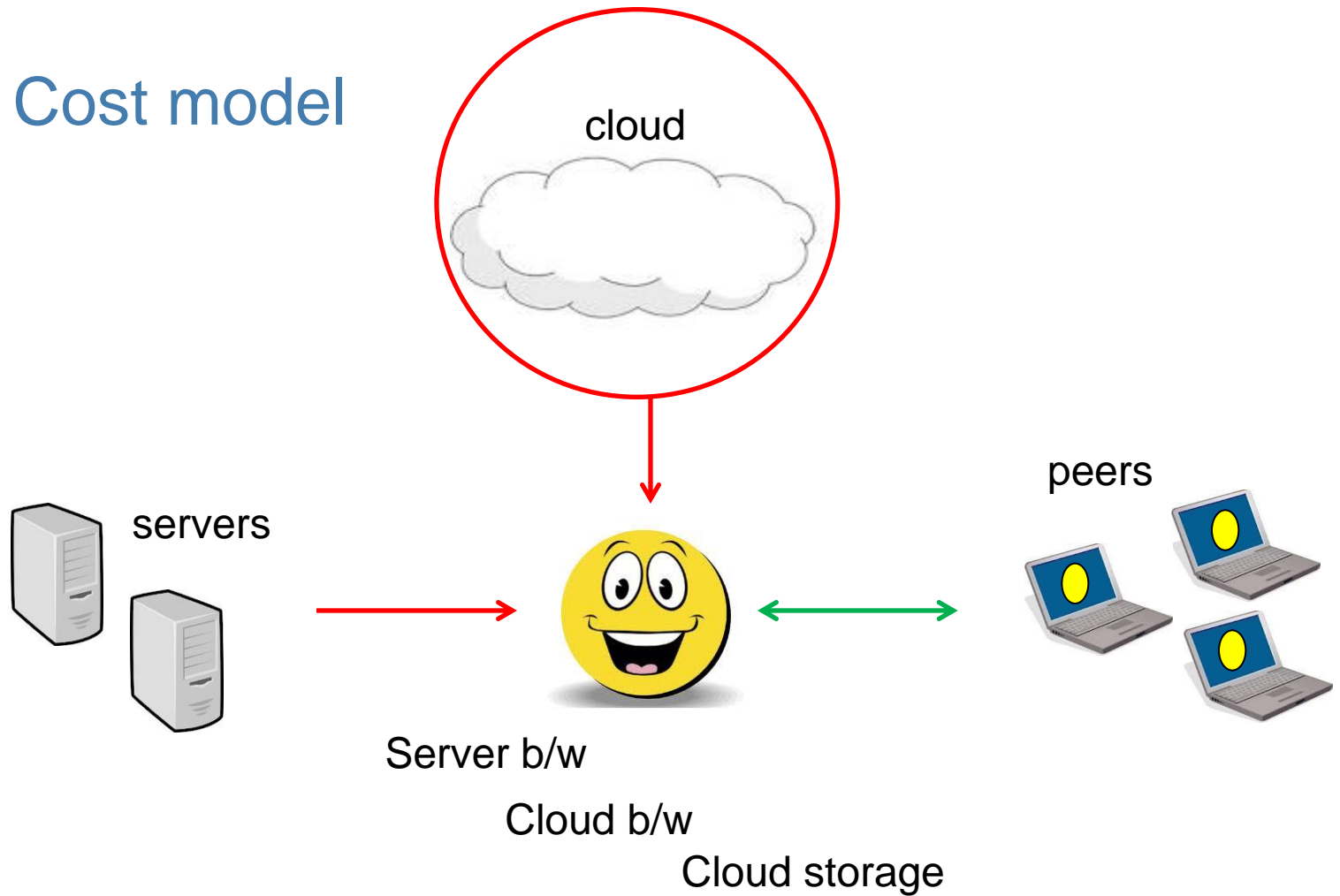
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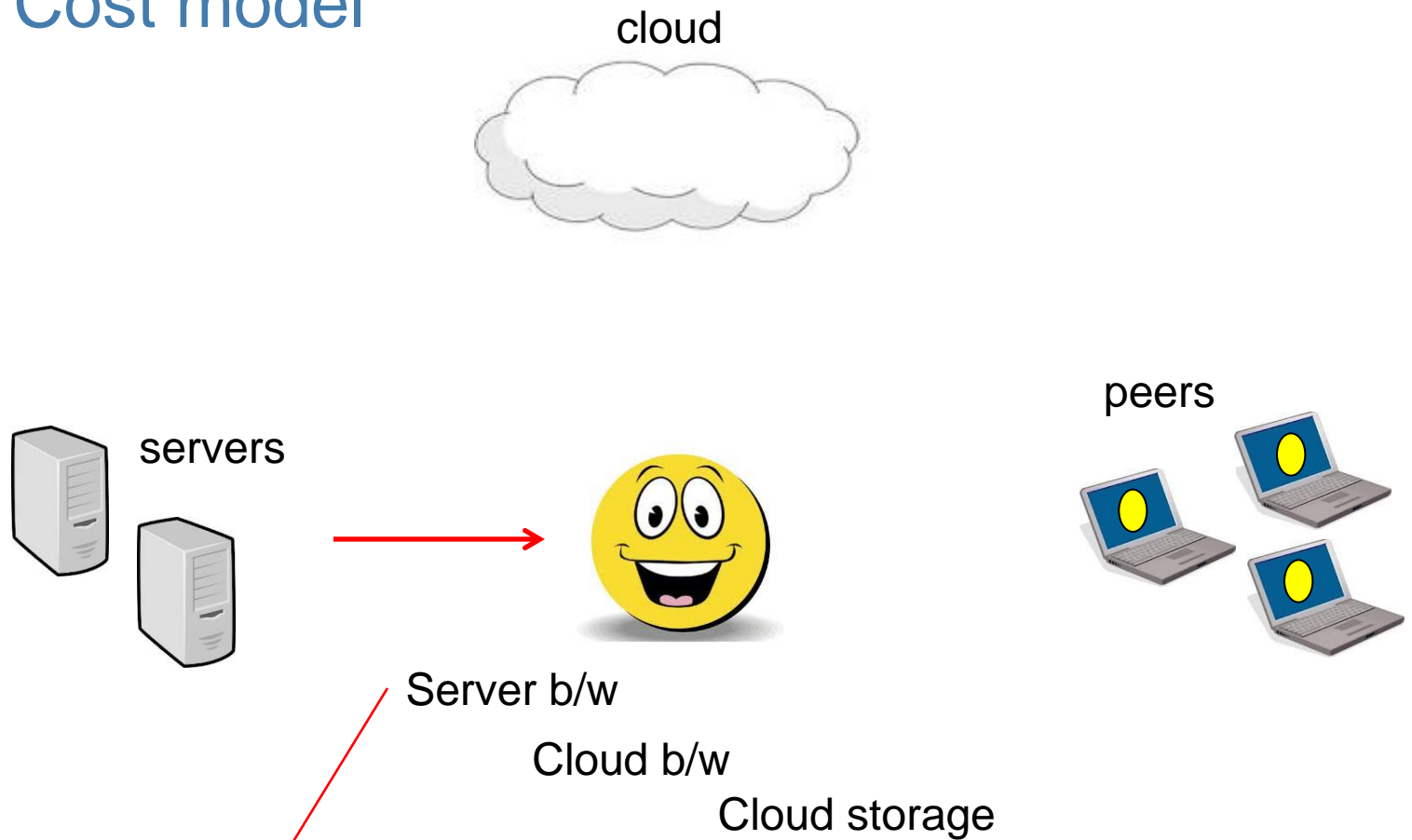
Cost model



$$\sum_{i \in N/M} B_i^s + c \sum_{i \in M} B_i^c + C |M|$$



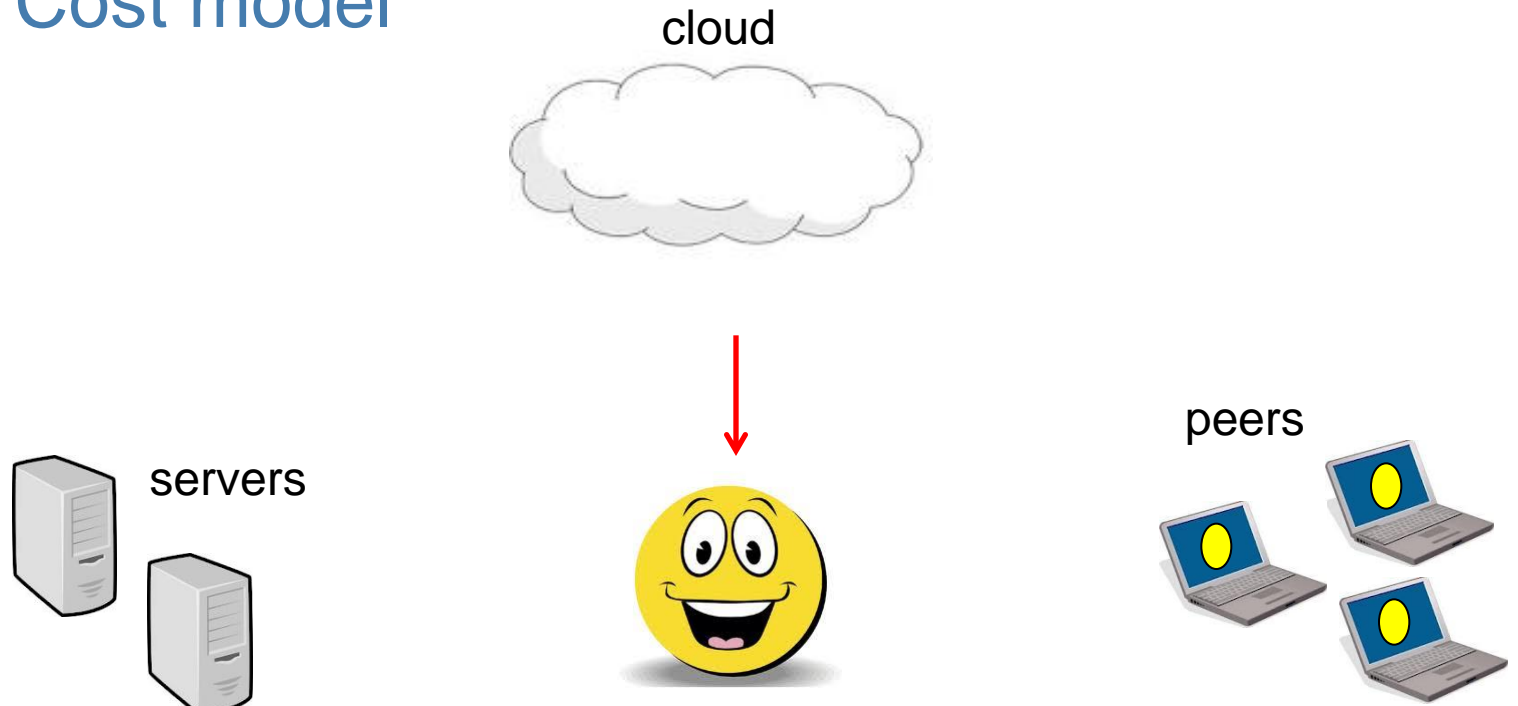
Cost model



$$\sum_{i \in N/M} B_i^s + c \sum_{i \in M} B_i^c + C |M|$$

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Cost model



Server b/w

Cloud b/w

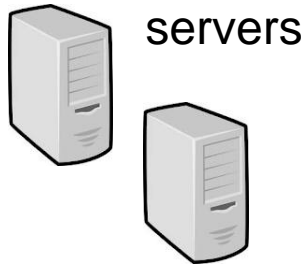
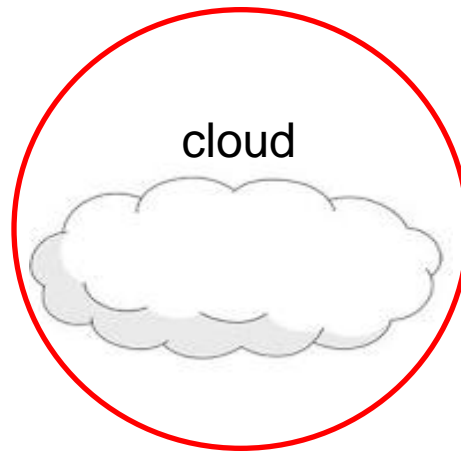
Cloud storage

$$\sum_{i \in N/M} B_i^s + c \sum_{i \in M} B_i^c + C |M|$$

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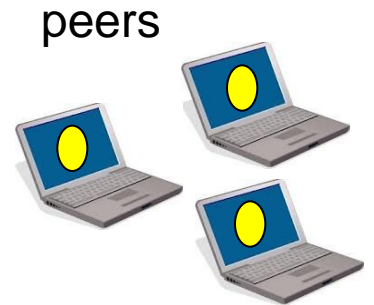


Cost model



Server b/w

Cloud b/w

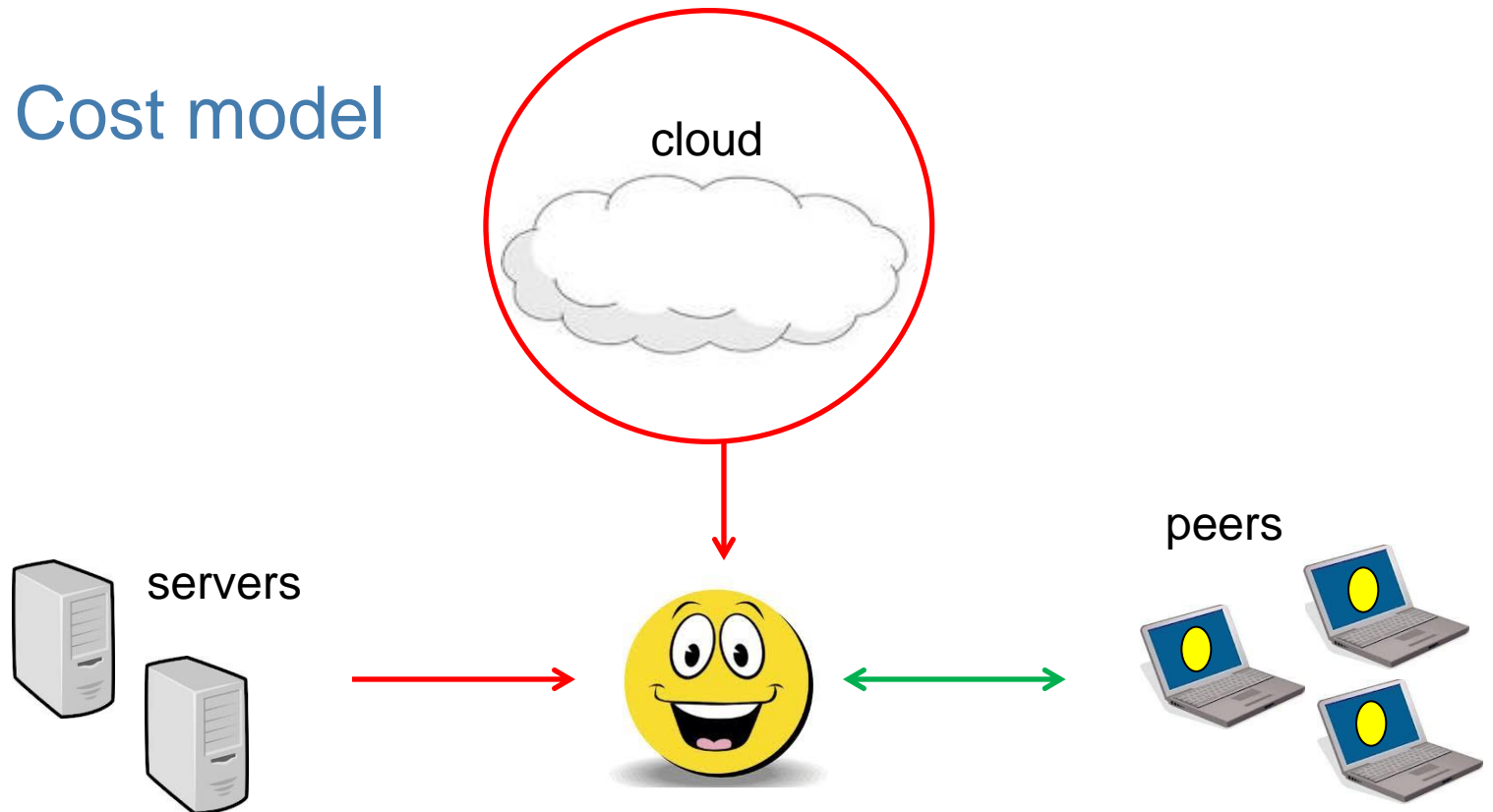


Cloud storage

$$\sum_{i \in N/M} B_i^s + c \sum_{i \in M} B_i^c + C |M|$$




Cost model



Server b/w

Cloud b/w

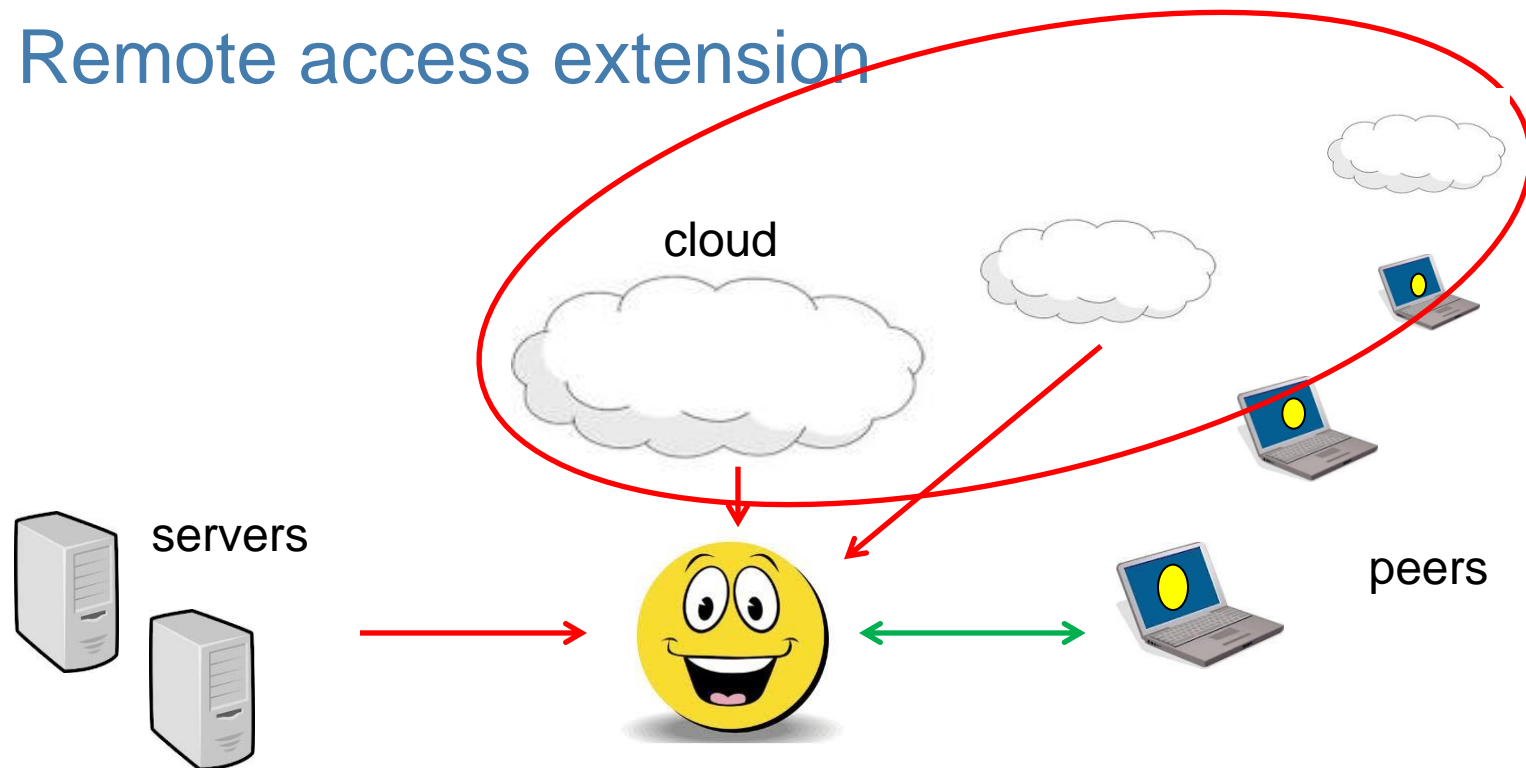
Cloud storage

$$\sum_{i \in N/M} B_i^s + c \sum_{i \in M} B_i^c + C |M|$$

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Remote access extension

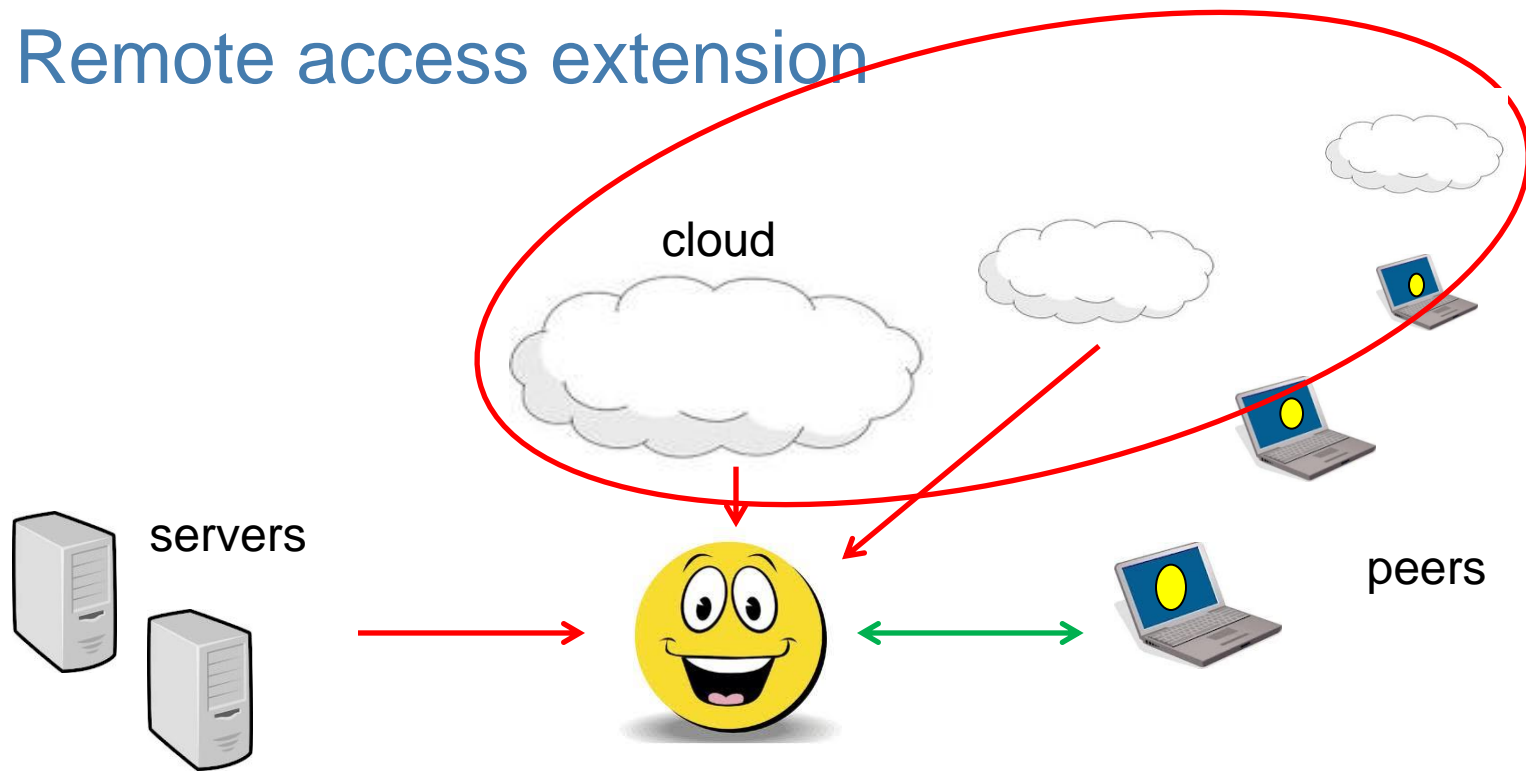


- Extensions
 - Full version (in paper)

$$\sum_{i \in N} B_i^s + c \sum_{i \in M} \sum_{j \in P_i} B_{i,j}^c (1 + q_{ij} f_{ij}) + C \sum_{i \in N} |P_i|$$



Remote access extension



- Extensions
 - Full version (in paper)

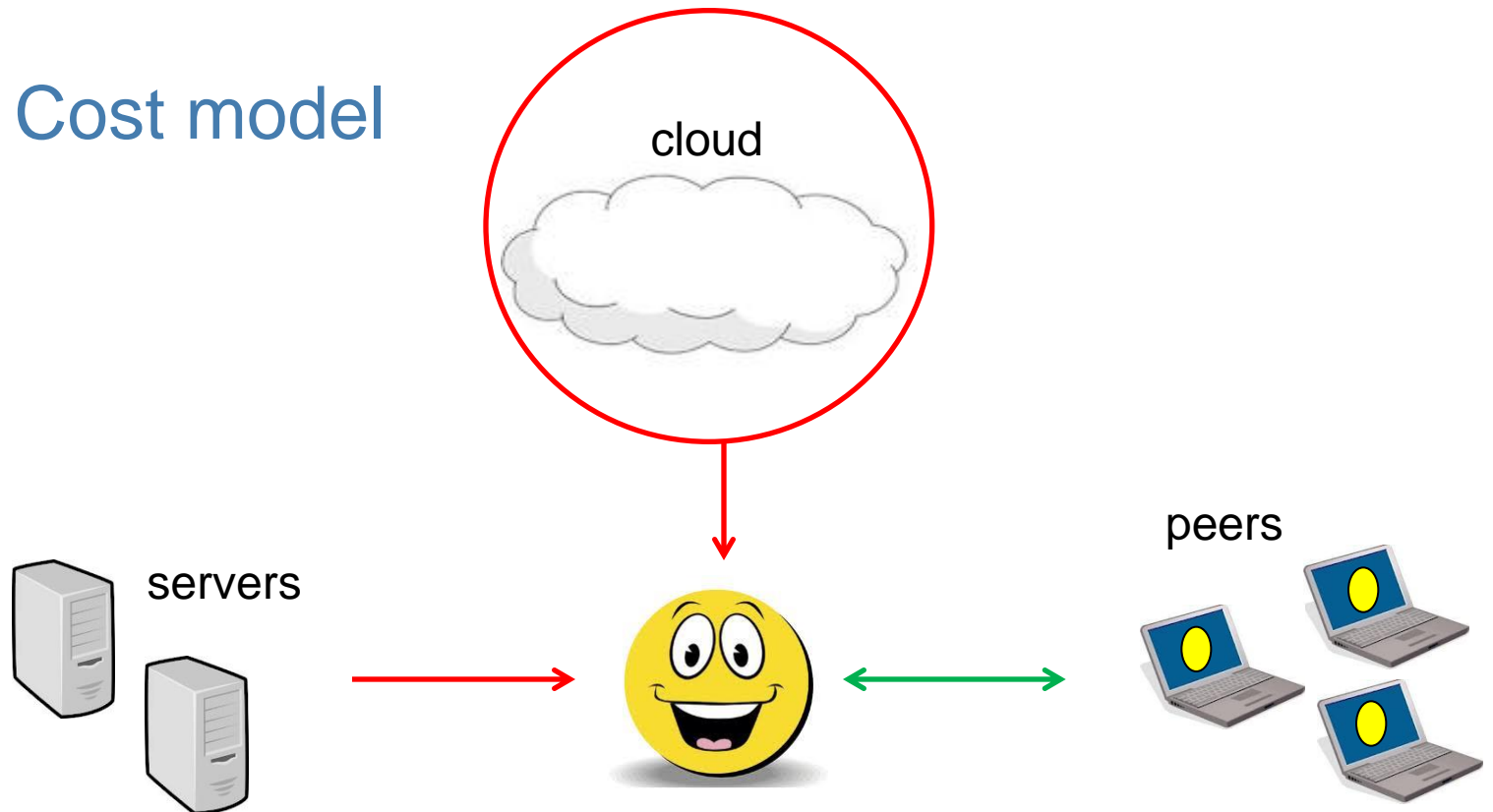
Different remote access cost

Locations of each content

$$\sum_{i \in N} B_i^s + c \sum_{i \in M} \sum_{j \in P_i} B_{i,j}^c (1 + q_{ij} f_{ij}) + C \sum_{i \in N} |P_i|$$



Cost model



Server b/w

Cloud b/w

Cloud storage

$$\sum_{i \in N/M} B_i^s + c \sum_{i \in M} B_i^c + C |M|$$

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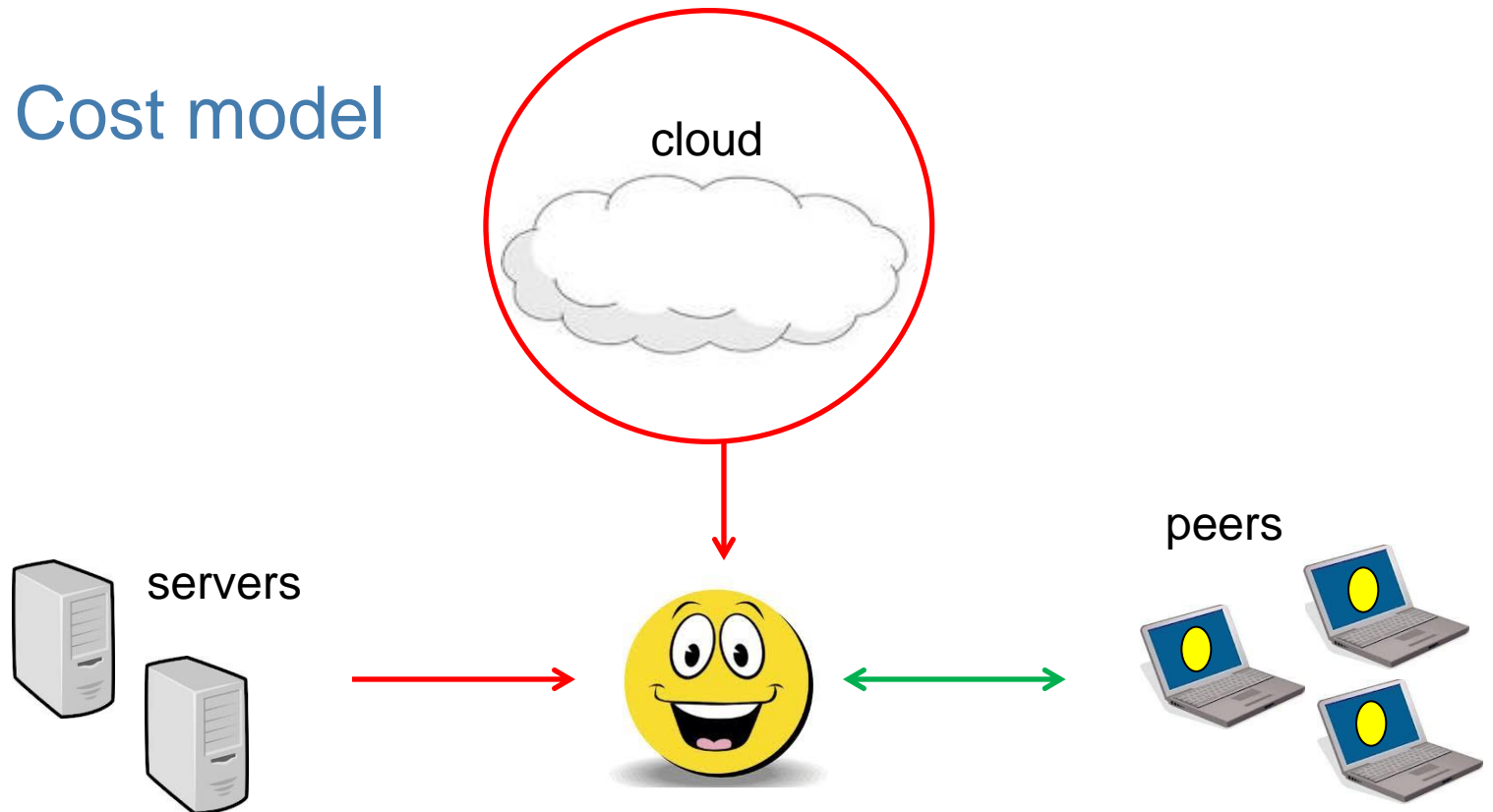
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- Aftär rätt, skade

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Cost model



Minimize

$$\sum_{i \in N/M} B_i^s + c \sum_{i \in M} B_i^c + C |M|$$

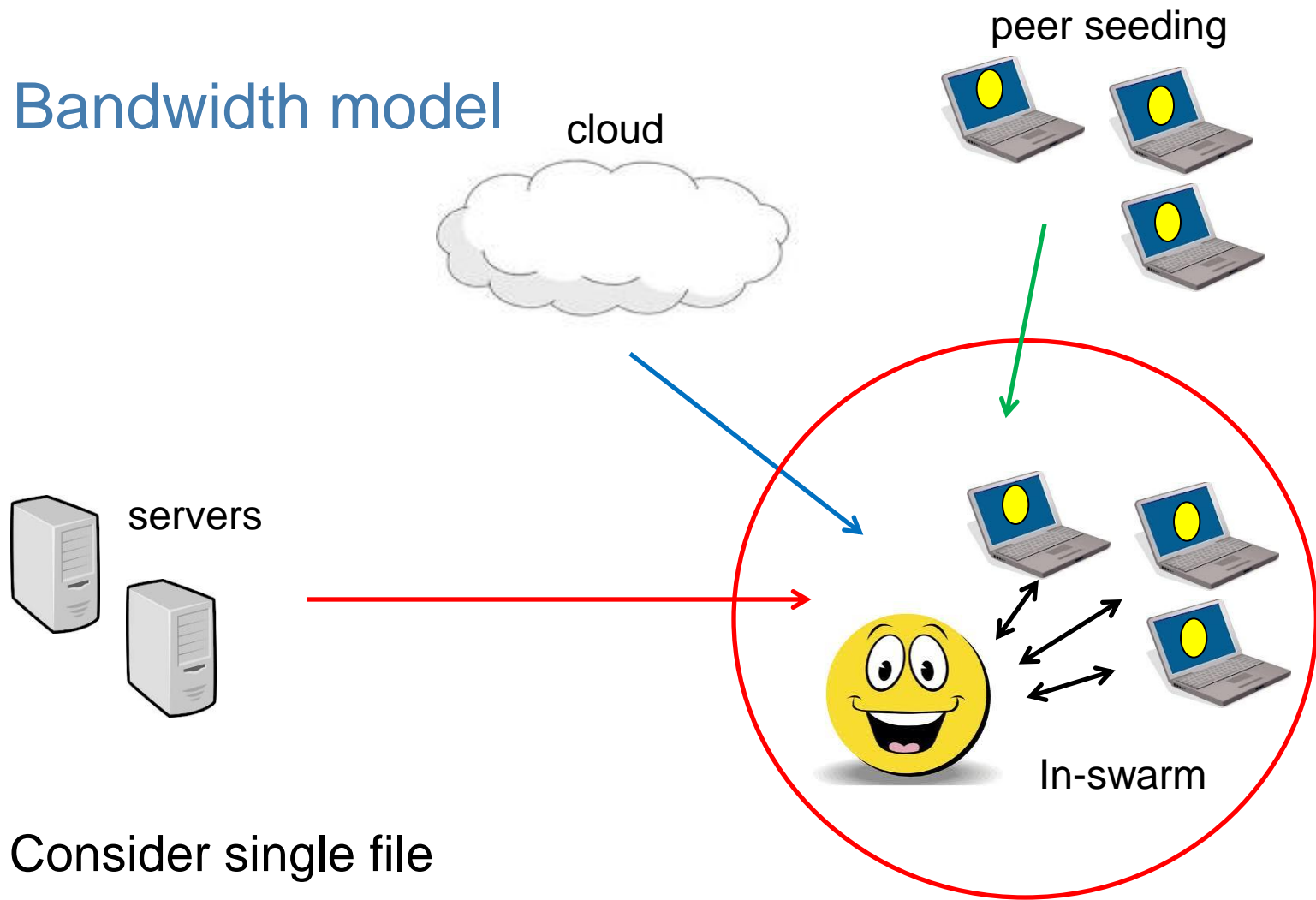
Labels for the equation components:

- Server b/w points to $\sum_{i \in N/M} B_i^s$
- Cloud b/w points to $c \sum_{i \in M} B_i^c$
- Cloud storage points to $C |M|$

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Bandwidth model



- Consider single file

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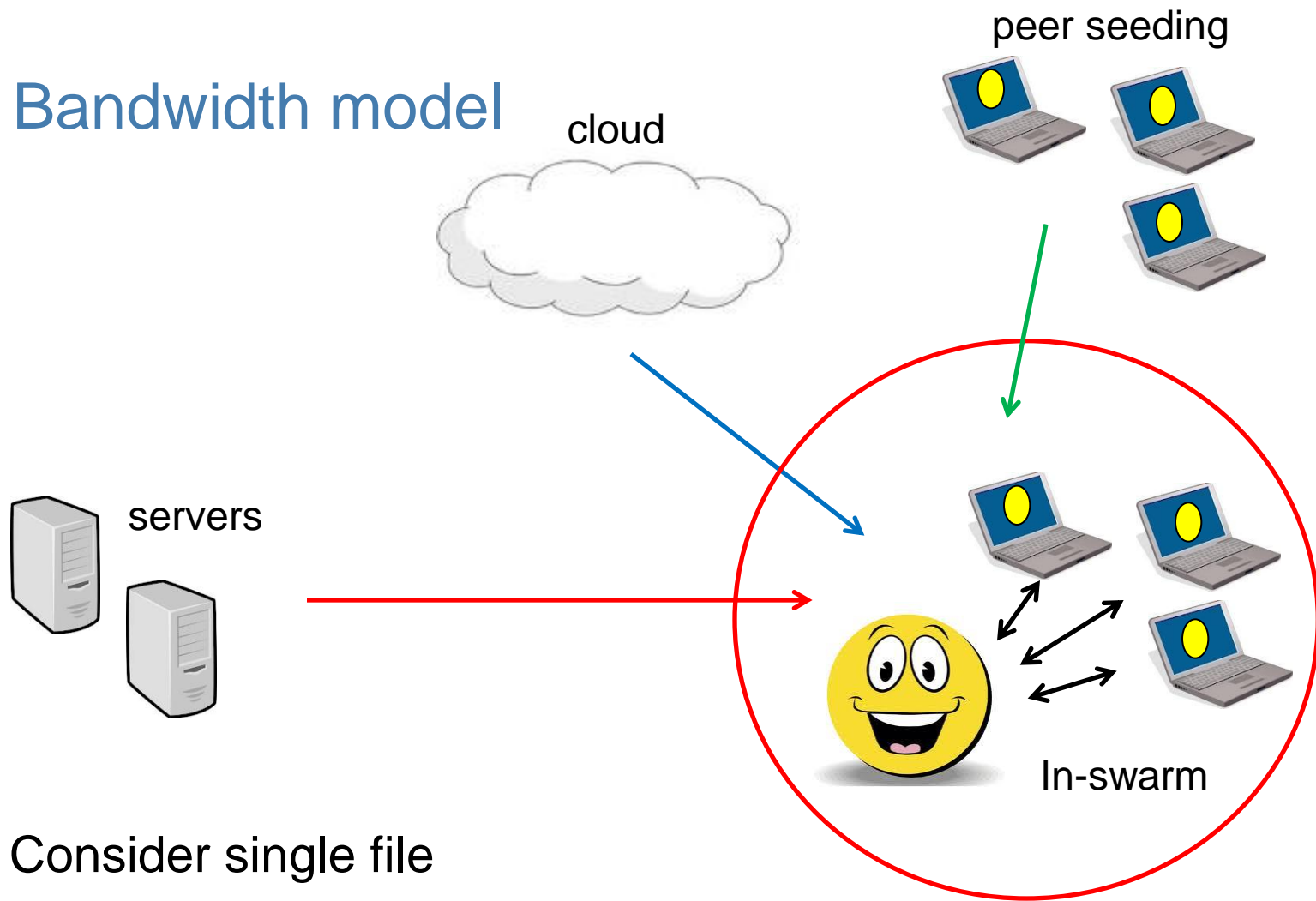
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Bandwidth model

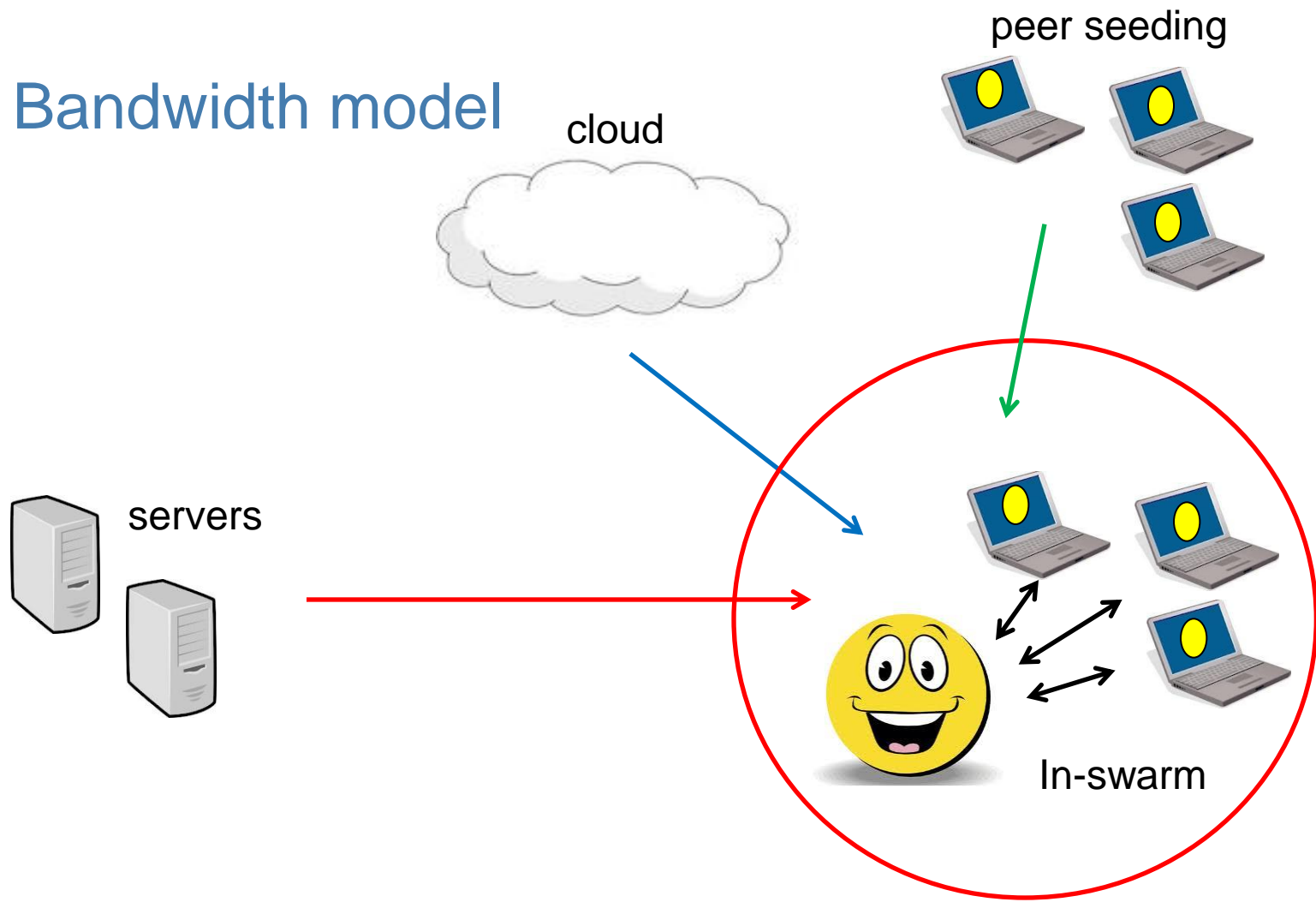


- Consider single file

$$B(\lambda_i + \phi_i) \leq B_i^s + \sum_{j \in P_i} B_{ij}^c + B_i^p$$



Bandwidth model

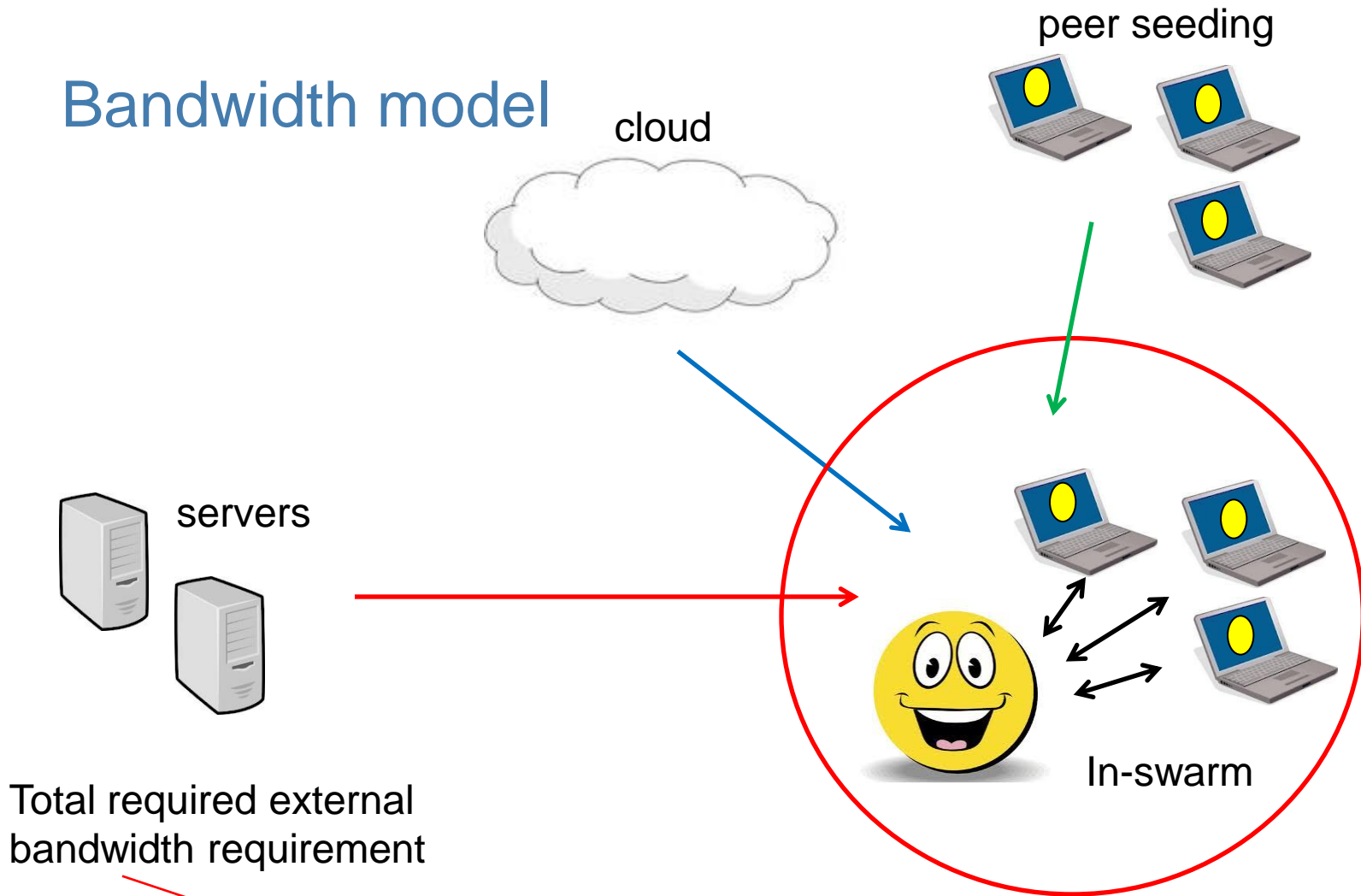


$$B(\lambda_i + \phi_i) \leq B_i^s + \sum_{j \in P_i} B_{ij}^c + B_i^p$$

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Bandwidth model



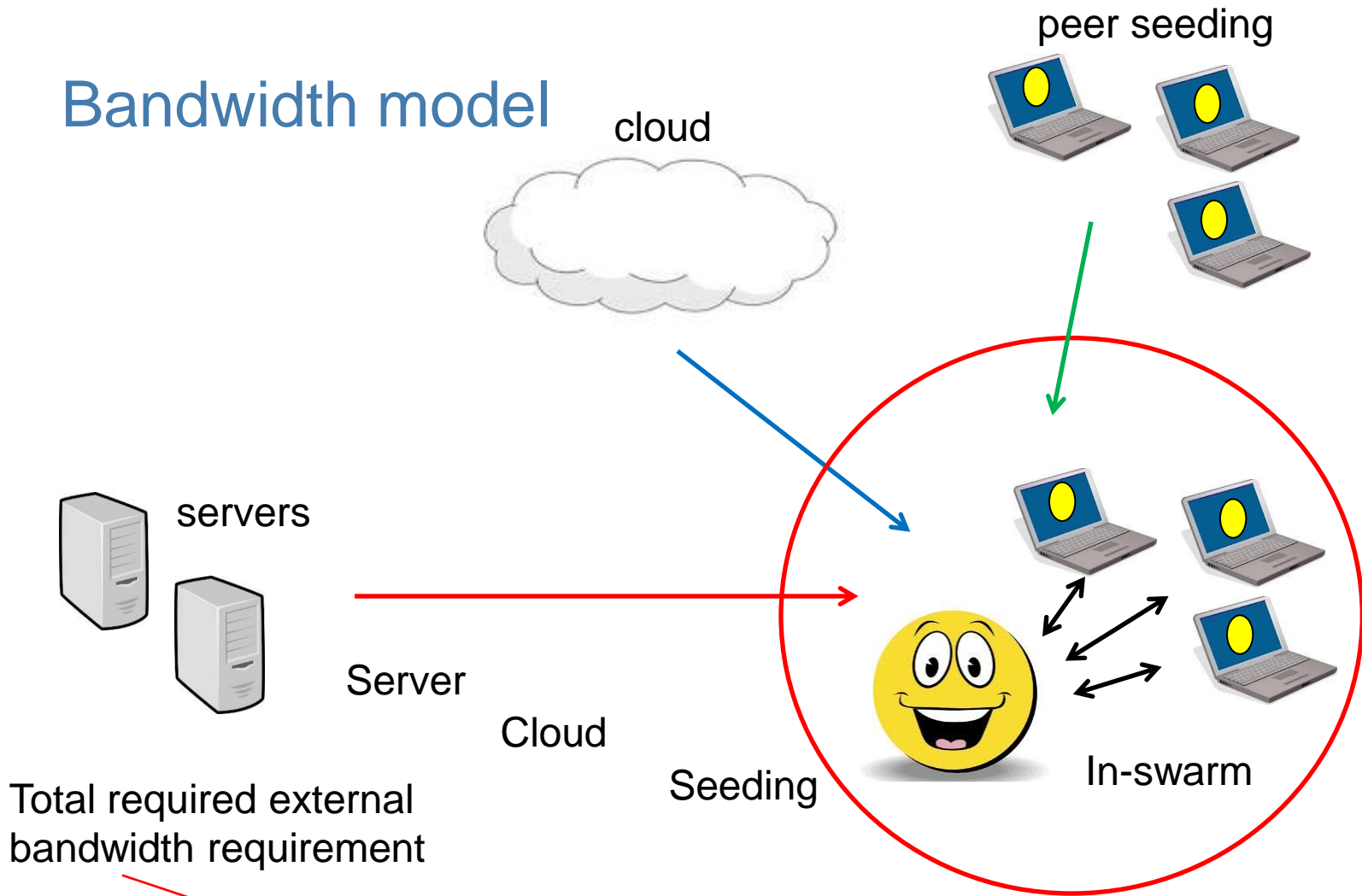
Total required external bandwidth requirement

$$B(\lambda_i + \phi_i) \leq B_i^s + \sum_{j \in P_i} B_{ij}^c + B_i^p$$

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Bandwidth model



Total required external bandwidth requirement

$$B(\lambda_i + \phi_i) \leq B_i^s + \sum_{j \in P_i} B_{ij}^c + B_i^p$$

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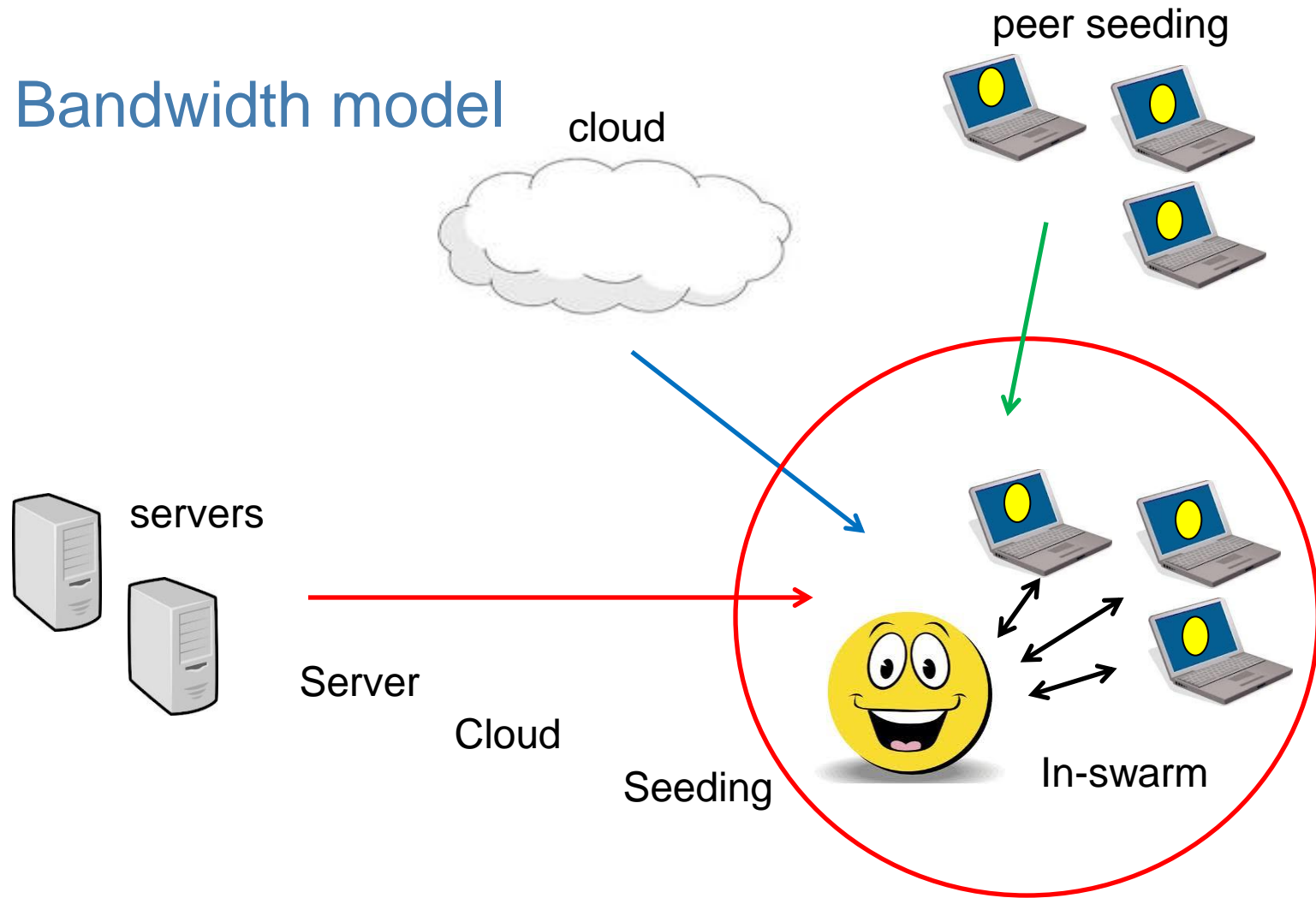
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Bandwidth model



$$B(\lambda_i + \phi_i) \leq B_i^s + \sum_{j \in P_i} B_{ij}^c + B_i^p$$

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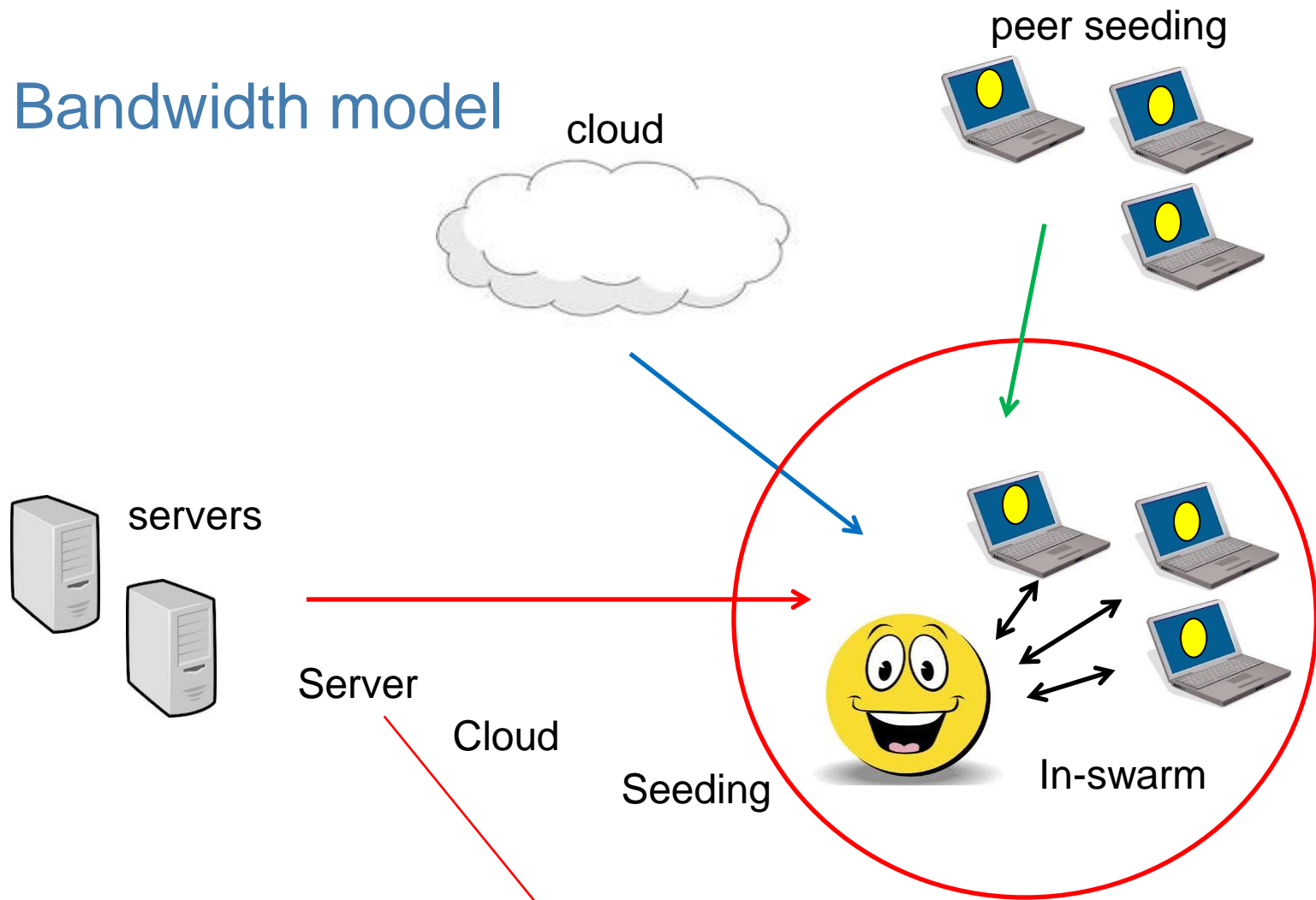
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Bandwidth model



$$B(\lambda_i + \phi_i) \leq B_i^s + \sum_{j \in P_i} B_{ij}^c + B_i^p$$

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 ENINU
 OZUbet

MÖBELDESIGN

ward's
 squis AHAT DÉBÉAT!!
 Por jucinte p

odford's daughter

Åvez-vous

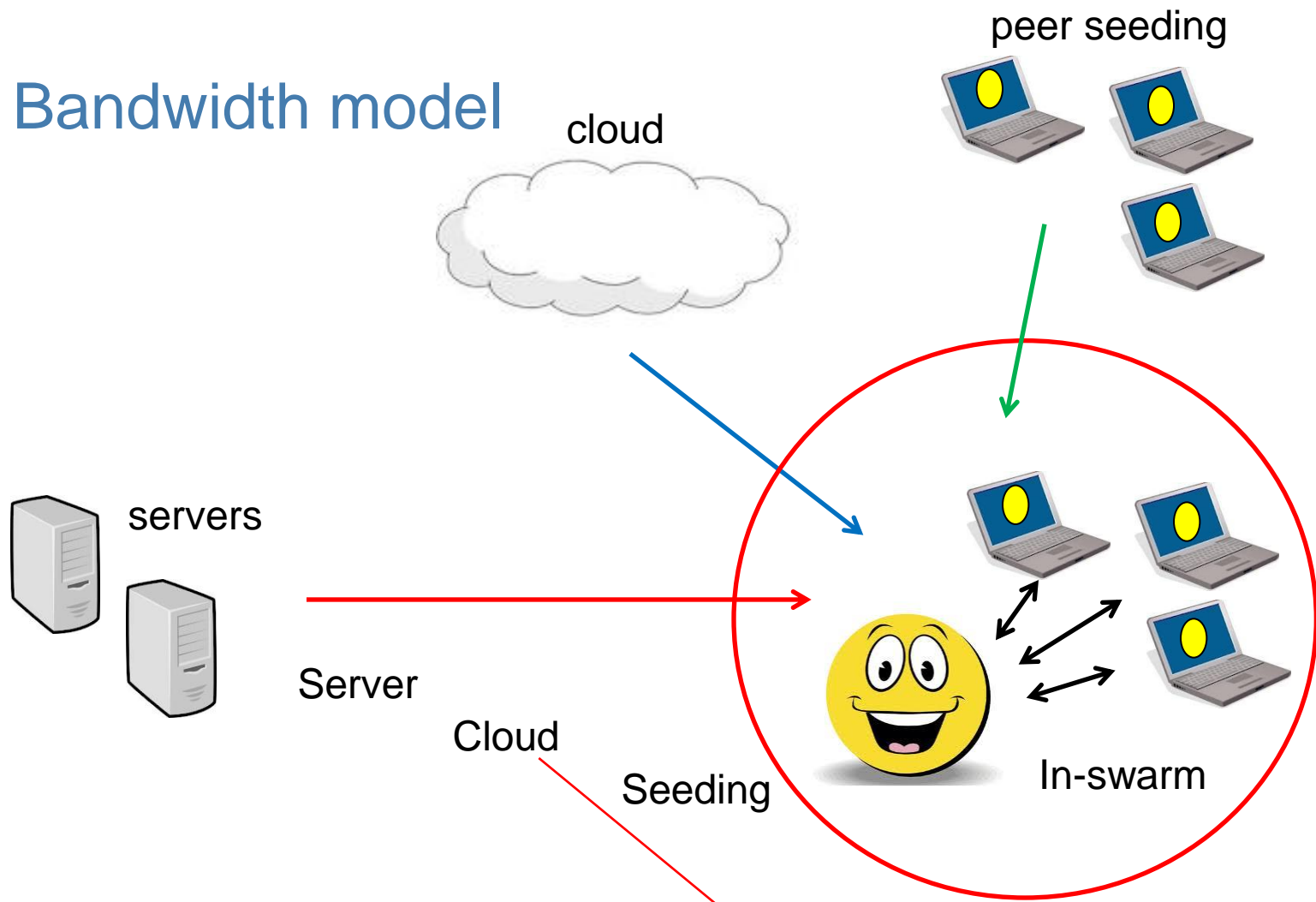
männi sko ej
 fter vad hon
 vad hon

- Rell teor och r
 - AHA r rät
 - Offentlig rät
 - AHA r rät, skade

On'li
 www.li.se

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Bandwidth model



$$B(\lambda_i + \phi_i) \leq B_i^s + \sum_{j \in P_i} B_{ij}^c + B_i^p$$

Just det att kiale
 får markeu sja
 dugarna med sja
 den paltbrödem
 det fruce on lada
 Och det fruce m
 som blanta riefat
 w masonu

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 OZUbet

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ward's
 squis AHAT DÉBÉAT!!
 Por jucinte p

odford's daughter

Åvez-vous

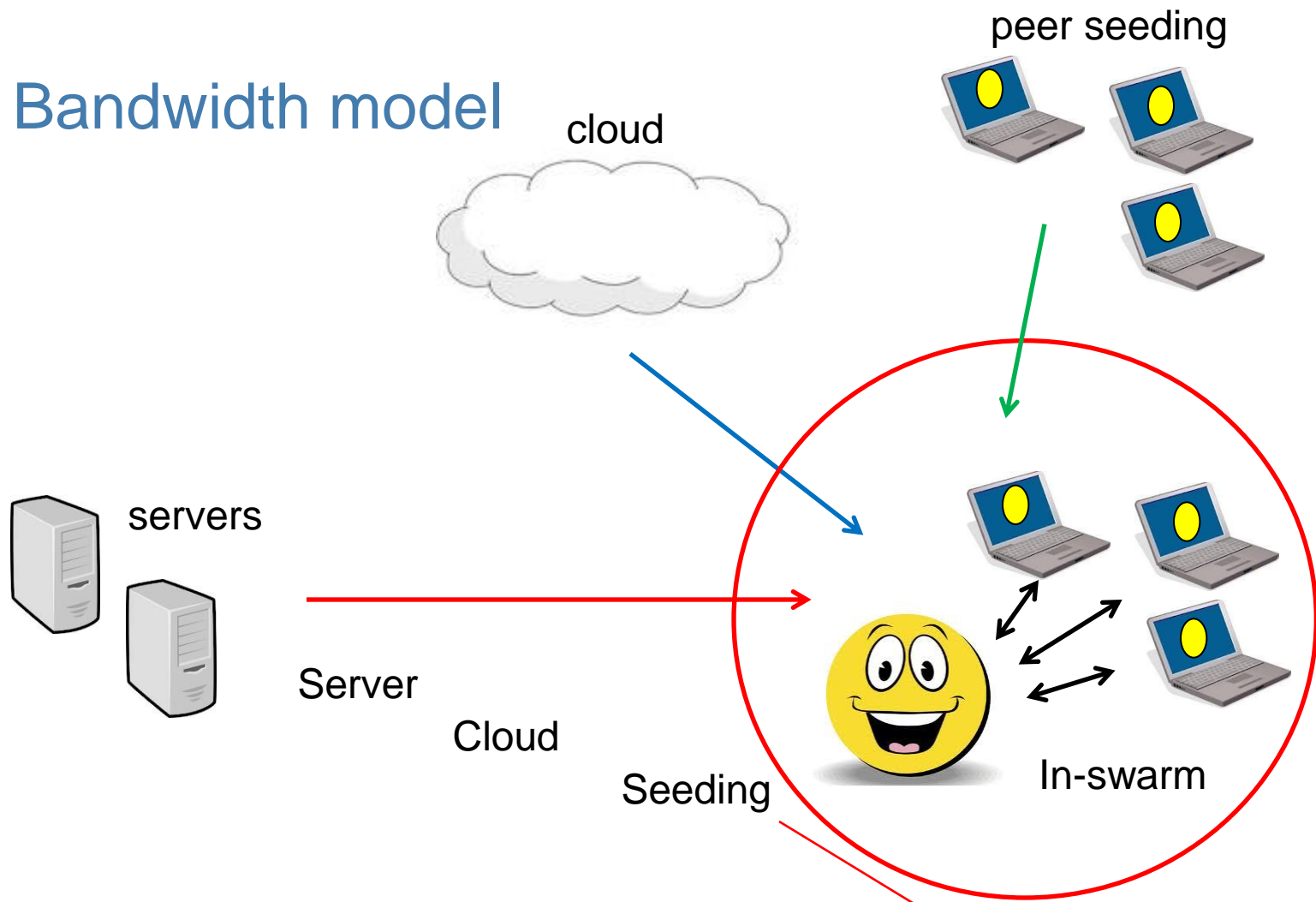
männi sko ej
 fter vad hon
 en vad hon

- Rell teor och ra
 - Affär crätt
 - Offentlig rätt
 - Atal crätt, skade

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Bandwidth model

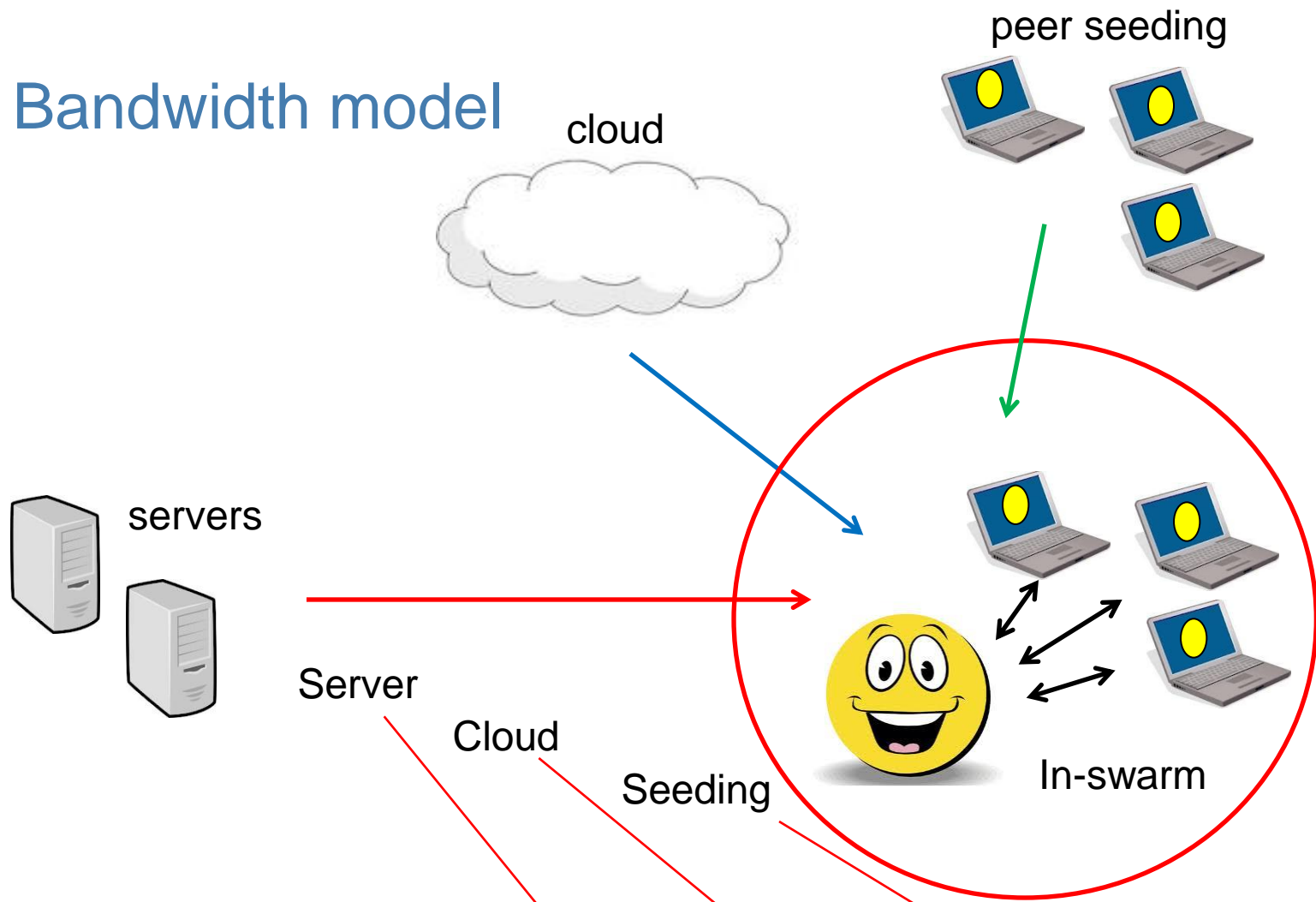


$$B(\lambda_i + \phi_i) \leq B_i^s + \sum_{j \in P_i} B_{ij}^c + B_i^p$$

Just det att k...
 får märken sjö...
 dingarna med s...
 den paltbröden...
 det finns en lada...
 Och det finns m...
 som blanda r...
 w m...
 ECKEN
 ENINU
 OZUDET
 MÖBELDESIGN
 words
 squis AHAT DÉBATE!!
 Por j...
 godford's daughter
 BY * K N P *
 P * P N Avez-vous
 P *
 minni sko ej
 fter vad hon
 en vad hon
 - Kell teor och r...
 - Affär r...
 - Offentlig r...
 - Atal r...
 OnLiU
 www.liu.se
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Bandwidth model



$$B(\lambda_i + \phi_i) \leq B_i^s + \sum_{j \in P_i} B_{ij}^c + B_i^p$$

Just det att kiale
 får markeu sja
 dugarna med sja
 den paltbrödem
 det fruce on lada
 Och det fruce m
 som blanta riefat
 w masonu

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ward's
 squis AHAT DÉBÉAT!!
 Por jucinte p

odford's daughter

AY x K N P x
 P x P N Avez-vous

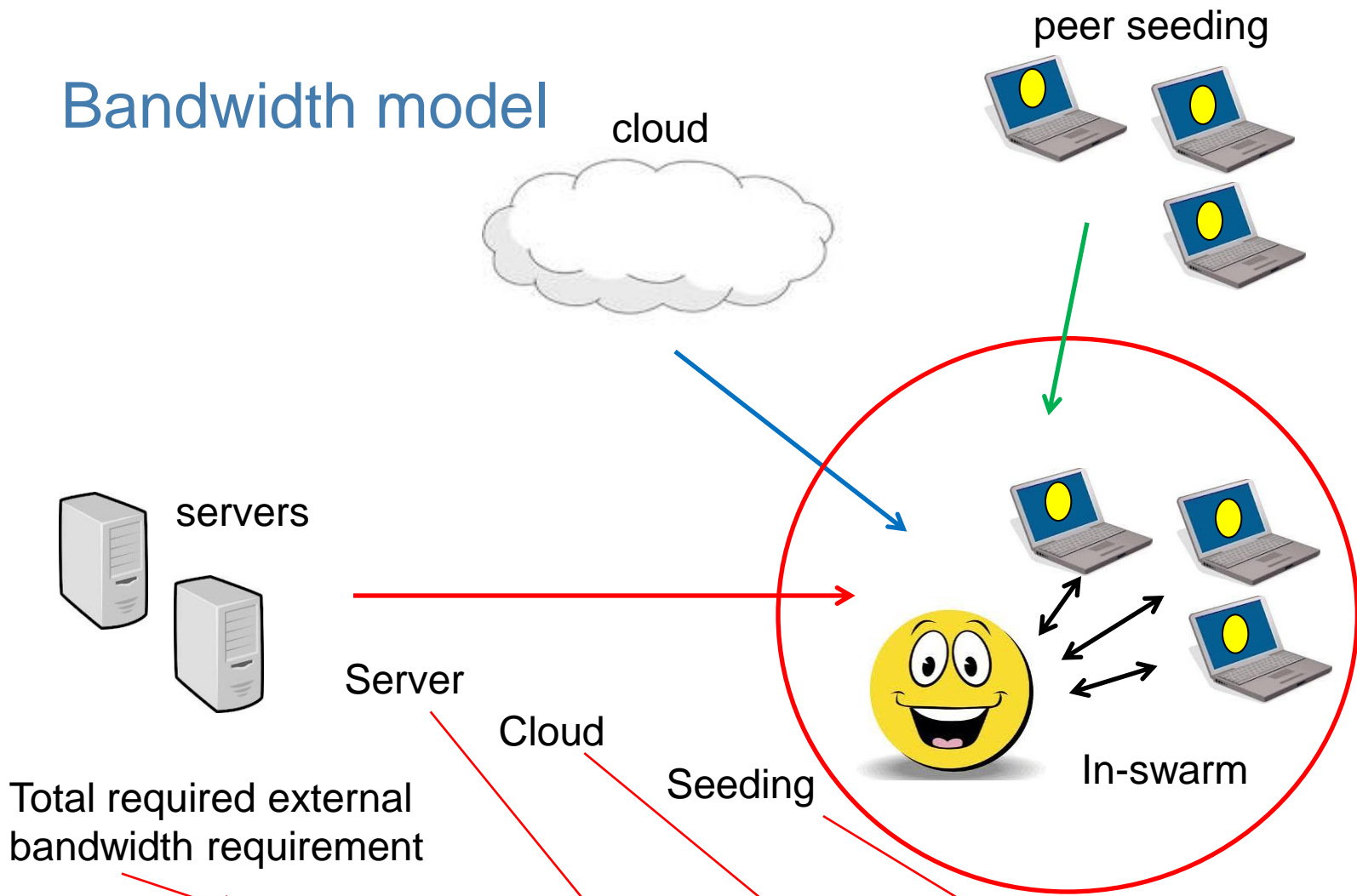
minni sko ej
 fter vad hon
 en vad hon

- Kell teor och ra
 - AHA crätt
 - Offentlig rätt
 - Atalcrätt, skade

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Bandwidth model



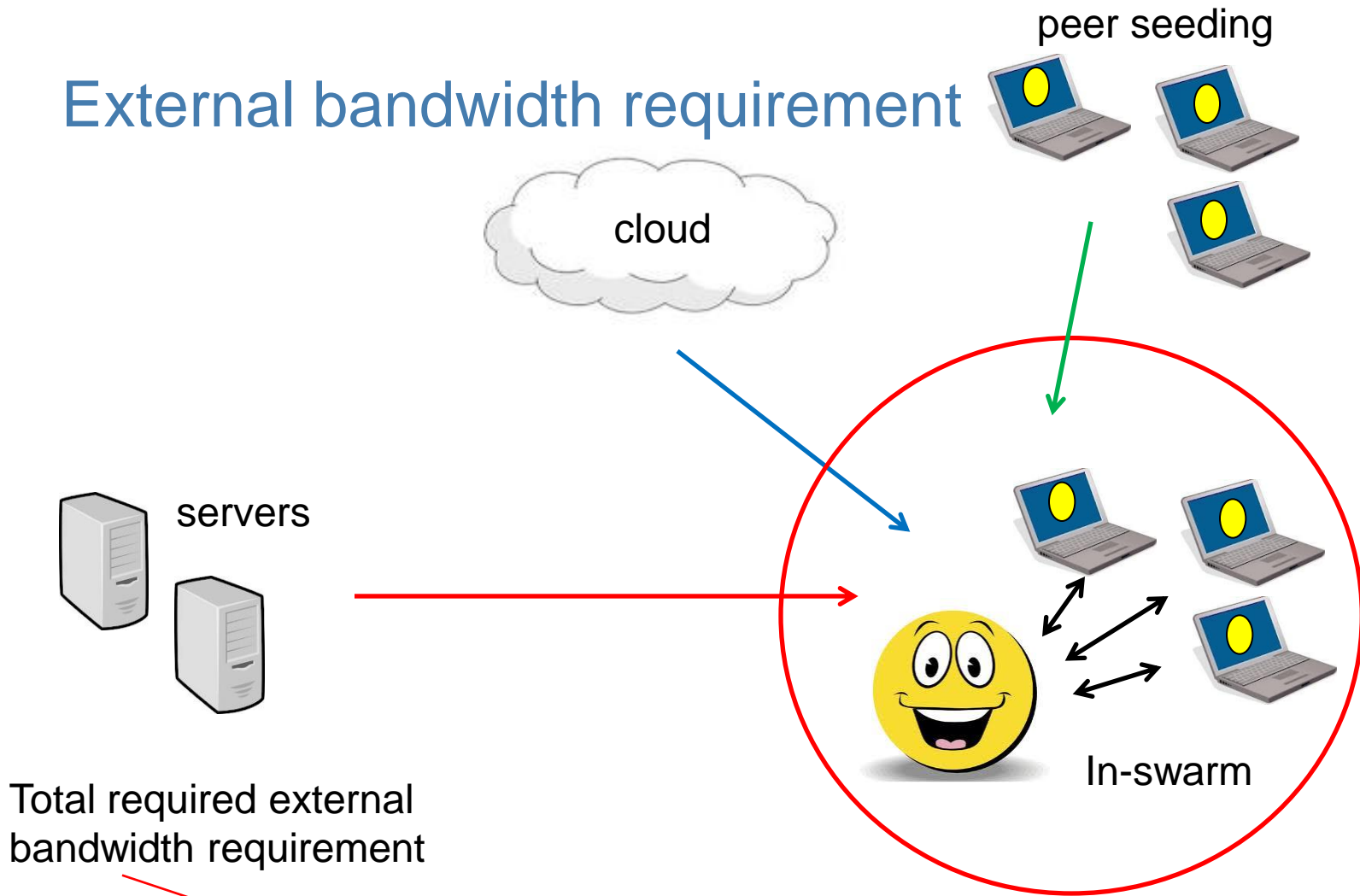
Total required external bandwidth requirement

$$B(\lambda_i + \phi_i) \leq B_i^s + \sum_{j \in P_i} B_{ij}^c + B_i^p$$

Just det att k...
 får marken sjö...
 dingarna med s...
 den paltbröden...
 det finns en lada...
 Och det finns m...
 som blanda r...
 w m...
 ECKEN
 ENINU
 OZUDET
 MÖBELDESIGN
 words
 squis AHAT DÉBATE!!
 Por jaginte p...
 doctord's daughter
 Åveç -vous
 minni sko ej
 fter vad hon
 vad hon
 - Kell teor och r...
 - Åttal crätt
 - Offentlig r...
 - Åttal crätt, skade
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External bandwidth requirement



Total required external bandwidth requirement

$$B(\lambda_i + \phi_i)$$

Just det att kiale
fär marcken sjö
dugarna med sif
den paltbrödem
det frunc on lada
Och det frunc m
som blanta riefat
w masonu

ECKEN
ENINU
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wards
SQUIS AHAT DÉREAT!!
Por jaginte p

odford's daughter

Åvez-vous

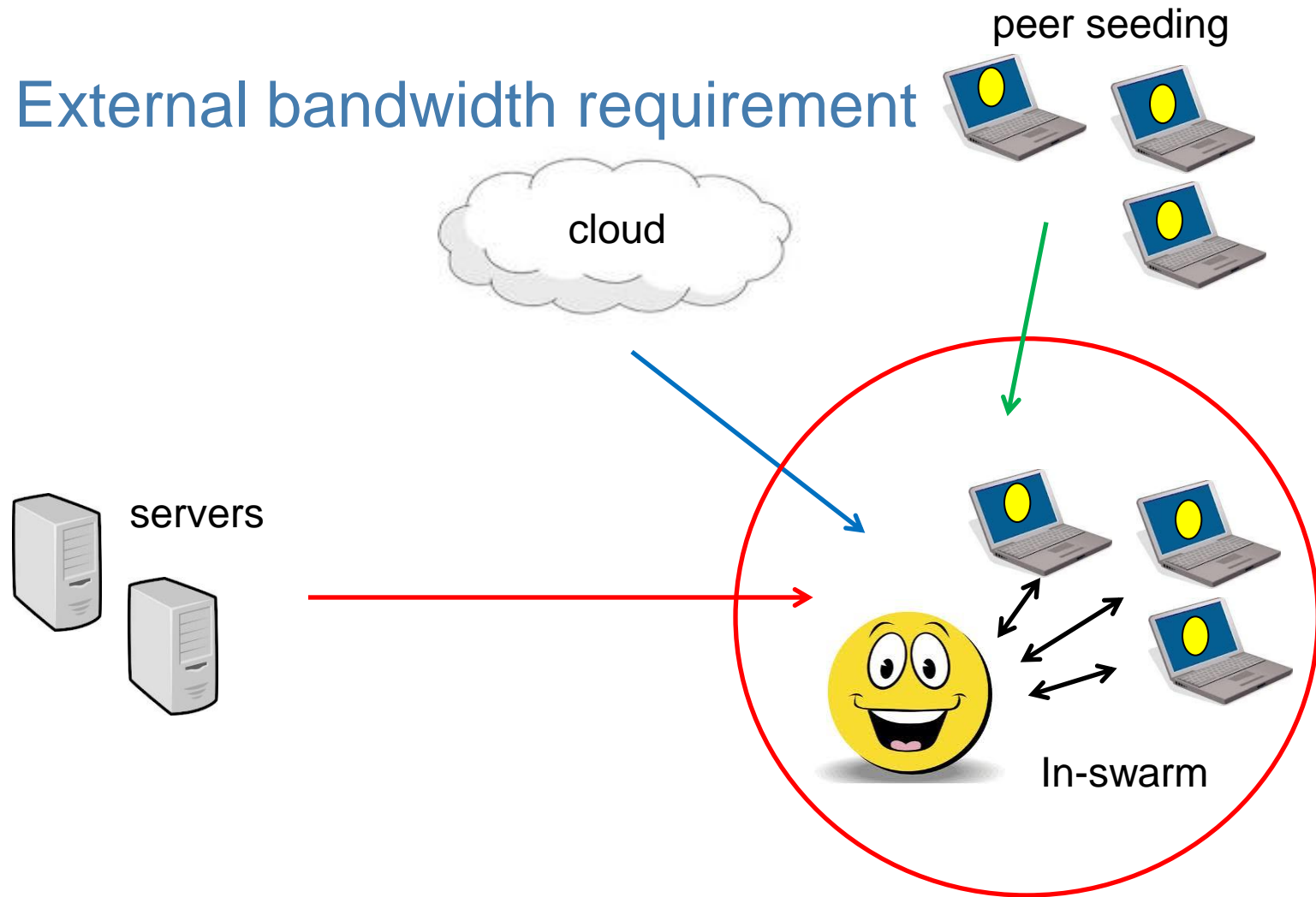
männi sko ej
fater vad hon
vad hon

- Rell teor och ra
- AHA crätt
- Offentlig rätt
- Ahtalcrätt, skade

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External bandwidth requirement



$$B(\lambda_i) \approx \lambda \sum_k^{\infty} \frac{(\lambda L / U)^k}{k!} e^{-\lambda L / U} \frac{k!}{(k+1)^k} L$$

Just det att kiale
fär marken sjä
dugarna med s
den paltbrödem
det frunc on lada
Och det frunc m
som blanta riefat
w masonu

ECKEN
ENINU
OZUbet

MÖBELDESIGN

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SQUIS AHAT DÉBÉAT!!
Por jucinte p

odford's daughter

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External bandwidth requirement

$$B(\lambda_i) \approx \lambda \sum_k^{\infty} \frac{(\lambda L / U)^k}{k!} e^{-\lambda L / U} \frac{k!}{(k+1)^k} L$$



External bandwidth requirement

- Consider **missing piece** policy
 - Server upload only one piece at a time whenever there is at least one piece missing among peer set

$$B(\lambda_i) \approx \lambda \sum_k \frac{(\lambda L / U)^k}{k!} e^{-\lambda L / U} \frac{k!}{(k+1)^k} L$$



External bandwidth requirement

- Consider **missing piece** policy
 - Server upload only one piece at a time whenever there is at least one piece missing among peer set
- Assume (for simplicity)
 - Poisson arrivals, piece fractions, and independent pieces on each peer

$$B(\lambda_i) \approx \lambda \sum_k \frac{(\lambda L / U)^k}{k!} e^{-\lambda L / U} \frac{k!}{(k+1)^k} L$$



External bandwidth requirement

- Consider **missing piece** policy
 - Server upload only one piece at a time whenever there is at least one piece missing among peer set
- Assume (for simplicity)
 - Poisson arrivals, piece fractions, and independent pieces on each peer

Departure rate

$$B(\lambda_i) \approx \lambda \sum_k \frac{(\lambda L / U)^k}{k!} e^{-\lambda L / U} \frac{k!}{(k+1)^k} L$$



External bandwidth requirement

- Consider **missing piece** policy
 - Server upload only one piece at a time whenever there is at least one piece missing among peer set
- Assume (for simplicity)
 - Poisson arrivals, piece fractions, and independent pieces on each peer

Leave k peers behind

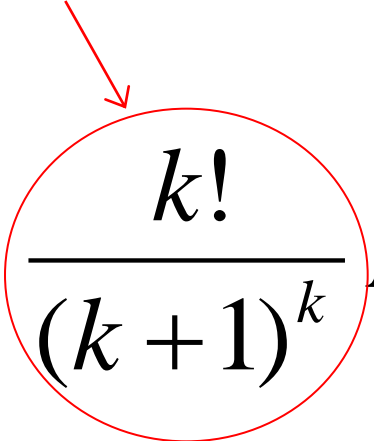
$$B(\lambda_i) \approx \lambda \sum_k \frac{(\lambda L / U)^k}{k!} e^{-\lambda L / U} \frac{k!}{(k+1)^k} L$$



External bandwidth requirement

- Consider **missing piece** policy
 - Server upload only one piece at a time whenever there is at least one piece missing among peer set
- Assume (for simplicity)
 - Poisson arrivals, piece fractions, and independent pieces on each peer

Peer k missing $1/(k+1)$
Peer $k-1$ missing $2/(k+1)$
...
Peer 1 missing $k/(k+1)$

$$B(\lambda_i) \approx \lambda \sum_k \frac{(\lambda L / U)^k}{k!} e^{-\lambda L / U} \frac{k!}{(k+1)^k} L$$




External bandwidth requirement

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...
Peer 1 missing $k/(k+1)$

Departure rate

Leave k peers behind

$$B(\lambda_i) \approx \lambda \sum_k^{\infty} \frac{(\lambda L / U)^k}{k!} e^{-\lambda L / U} \frac{k!}{(k+1)^k} L$$



External bandwidth requirement

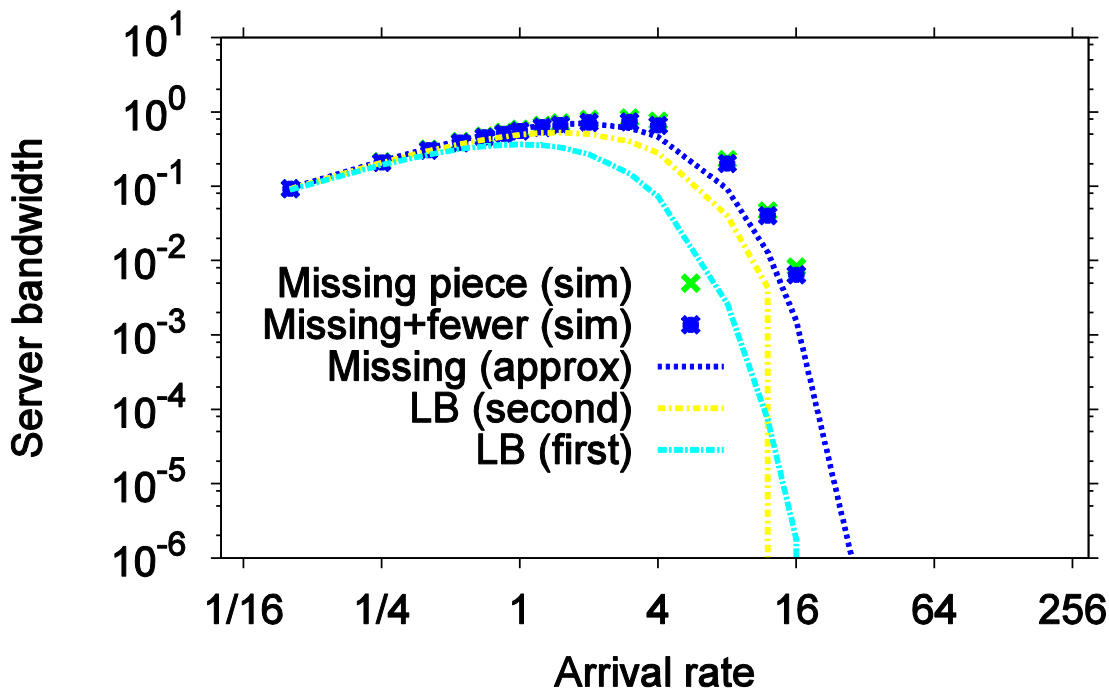
- Consider **missing piece** policy
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 - Poisson arrivals, piece fractions, and independent pieces on each peer

$$B(\lambda_i) \approx \lambda \sum_k \frac{(\lambda L / U)^k}{k!} e^{-\lambda L / U} \frac{k!}{(k+1)^k} L$$



External bandwidth requirement

- Consider **missing piece** policy
 - Server upload only one piece at a time whenever there is at least one piece missing among peer set

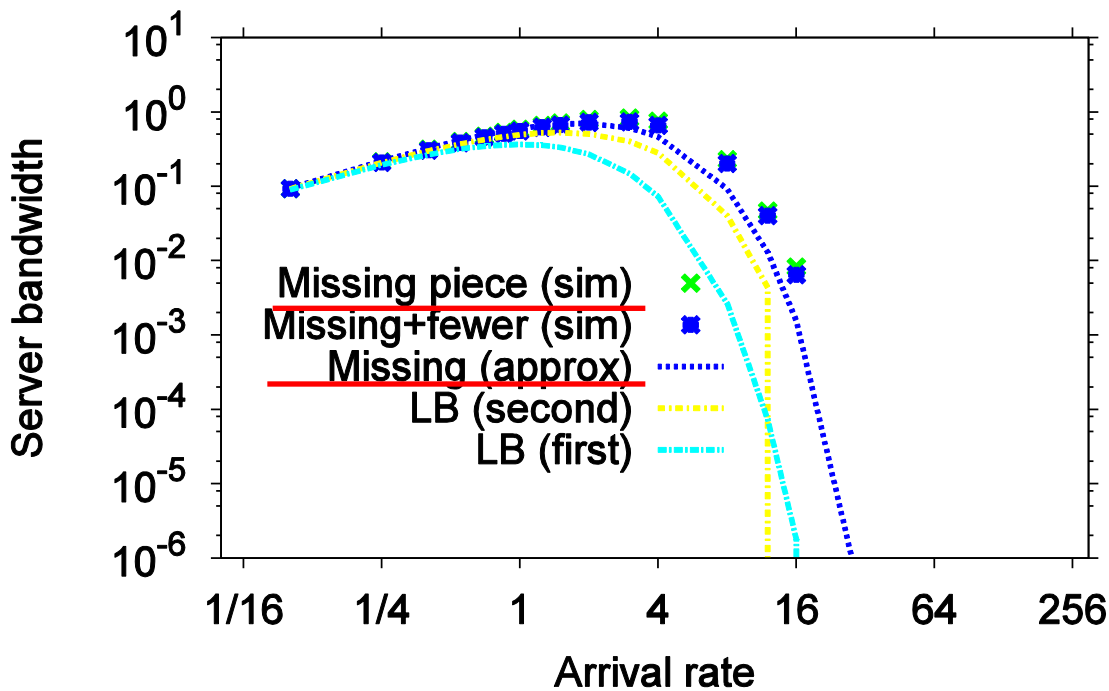


- Approximation fairly accurate
- Very small benefit prioritizing young peers (with few pieces)
- Self sustainability



External bandwidth requirement

- Consider **missing piece** policy
 - Server upload only one piece at a time whenever there is at least one piece missing among peer set

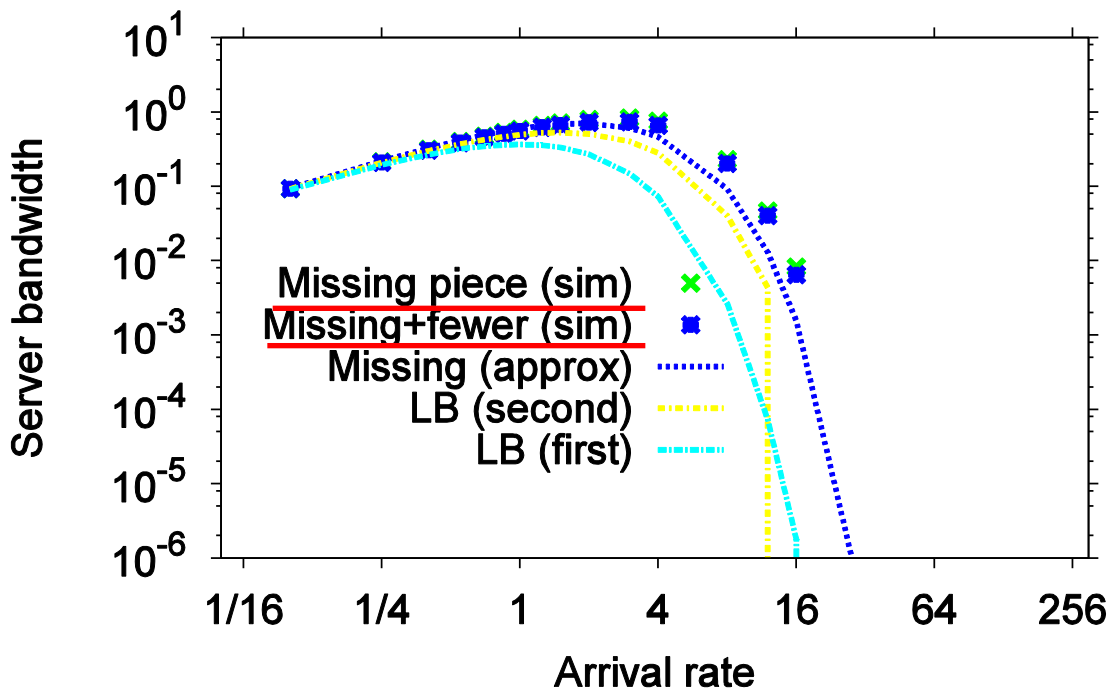


- **Approximation fairly accurate**
- Very small benefit prioritizing young peers (with few pieces)
- Self sustainability



External bandwidth requirement

- Consider **missing piece** policy
 - Server upload only one piece at a time whenever there is at least one piece missing among peer set

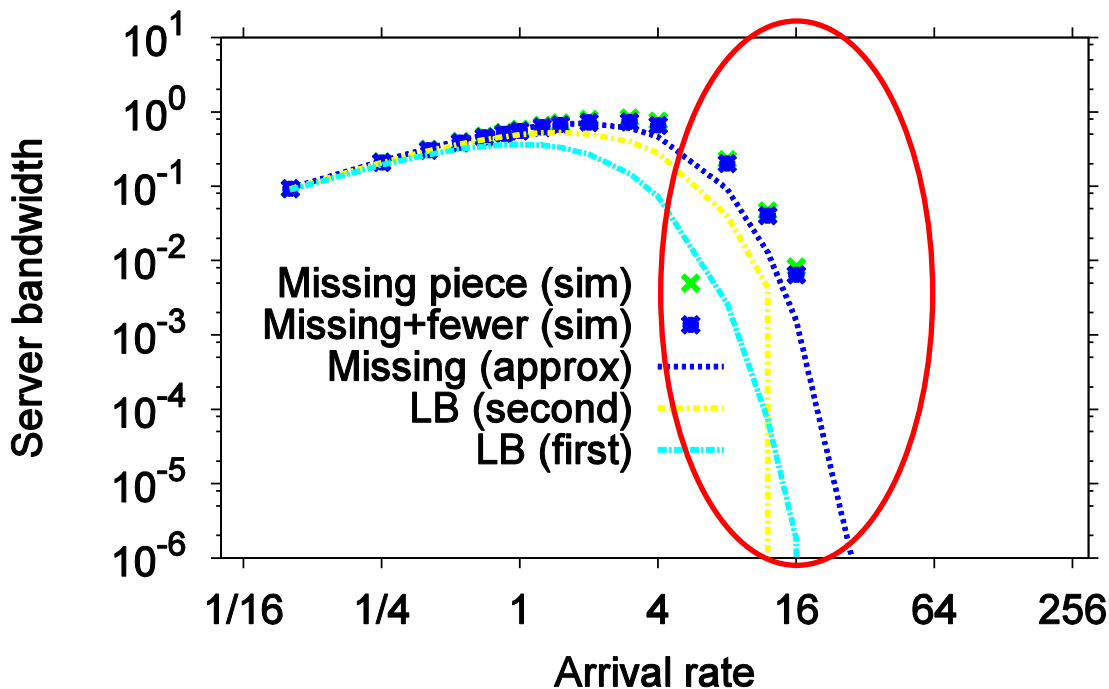


- Approximation fairly accurate
- Very small benefit prioritizing young peers (with few pieces)
- Self sustainability



Self sustainability

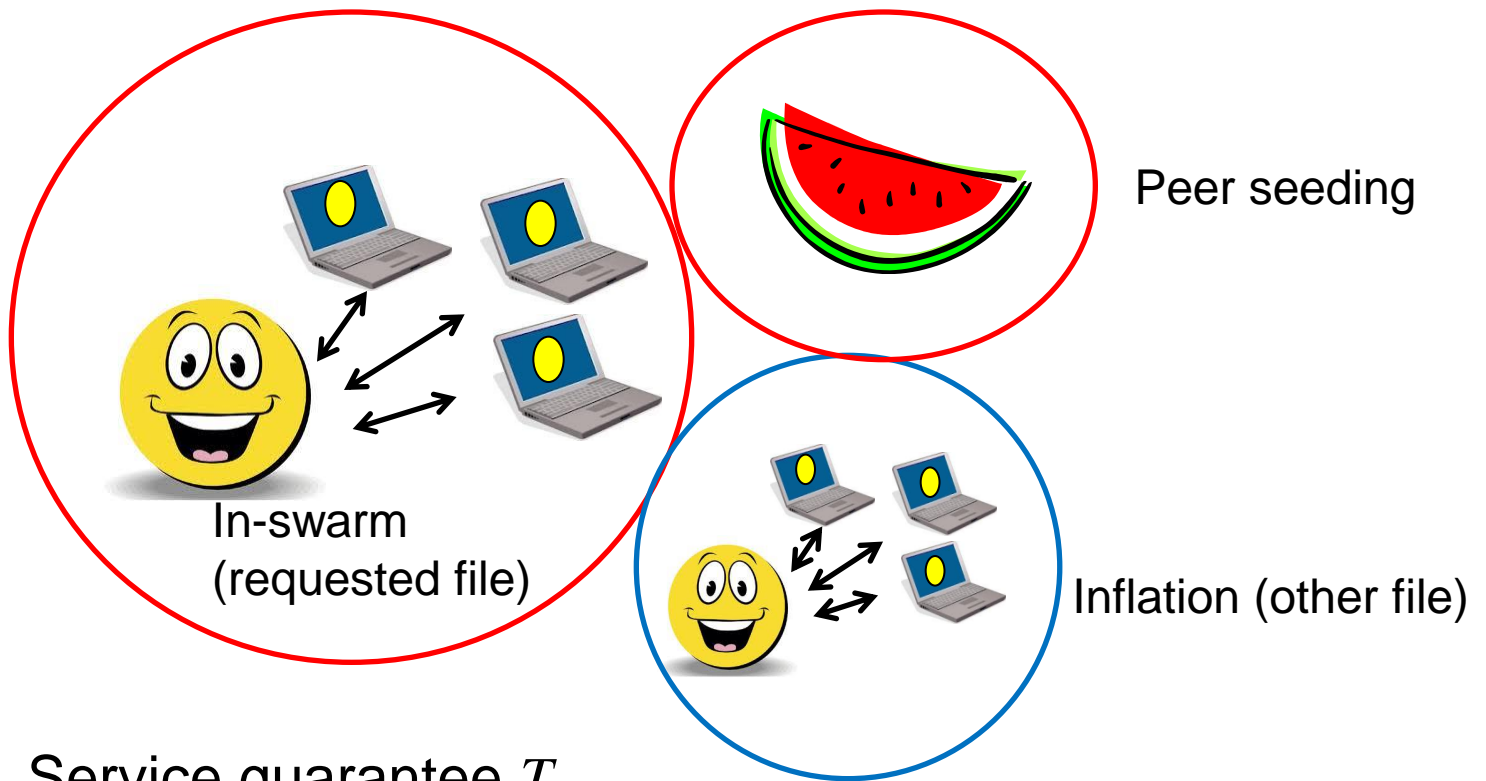
- Consider **missing piece** policy
 - Server upload only one piece at a time whenever there is at least one piece missing among peer set



- Approximation fairly accurate
- Very small benefit prioritizing young peers (with few pieces)
- **Self sustainability**



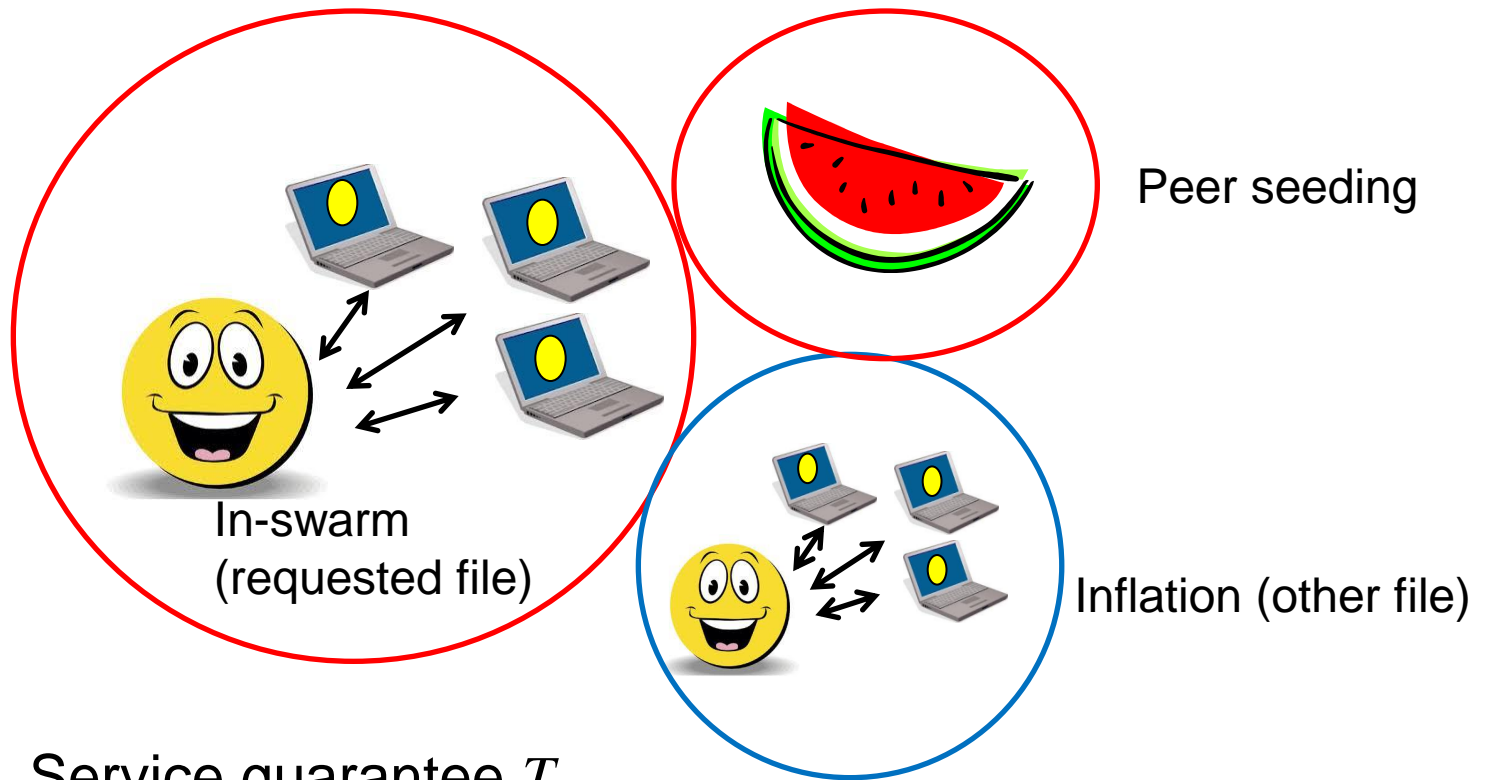
Peer upload bandwidth



- Service guarantee T
- Help out, but **only** during download/service



Peer upload bandwidth

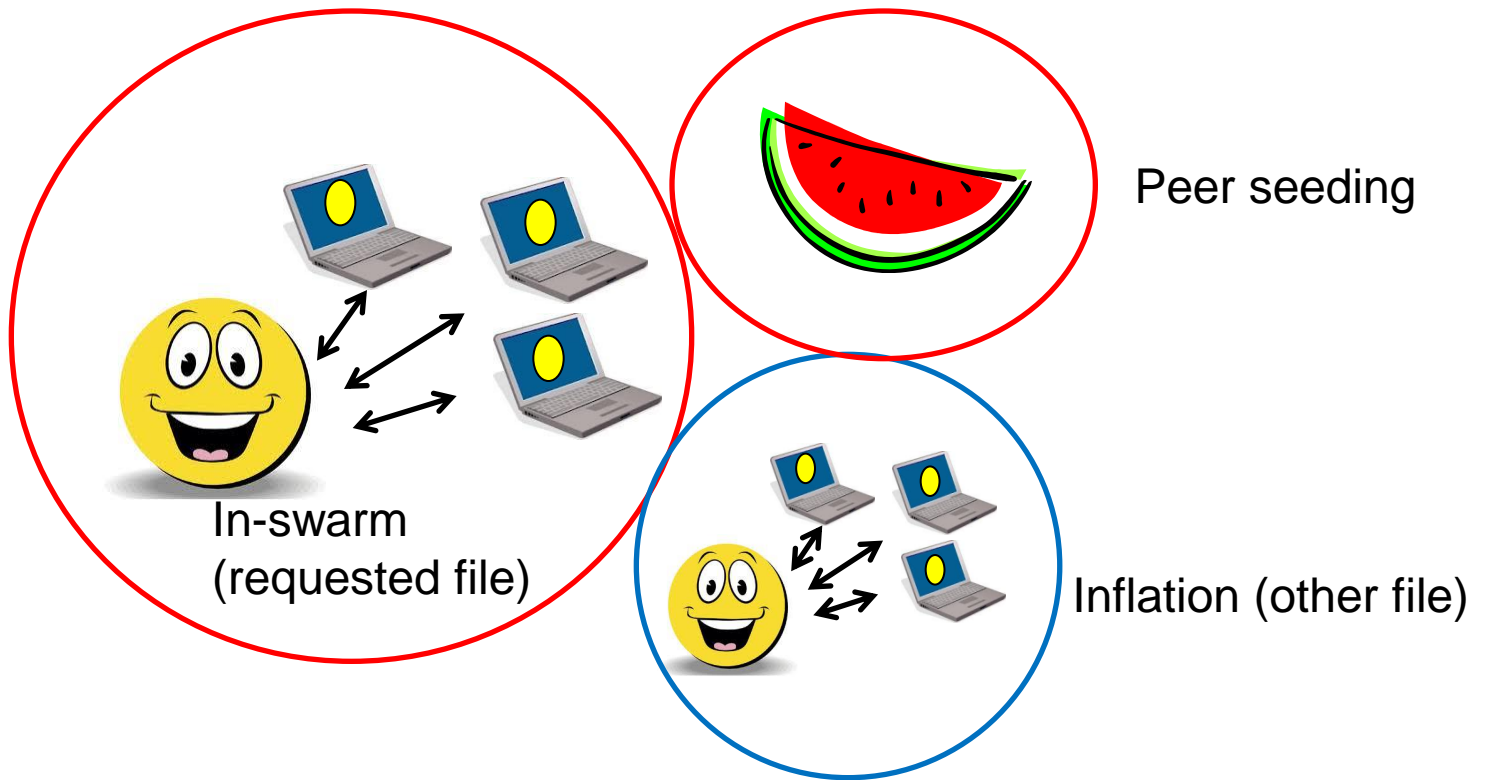


- Service guarantee T
- Help out, but **only** during download/service

$$\sum_{i \in N} \phi_i L + \sum_{i \in N} B_i^p \leq \sum_{i \in N} \lambda_i (UT - L)$$



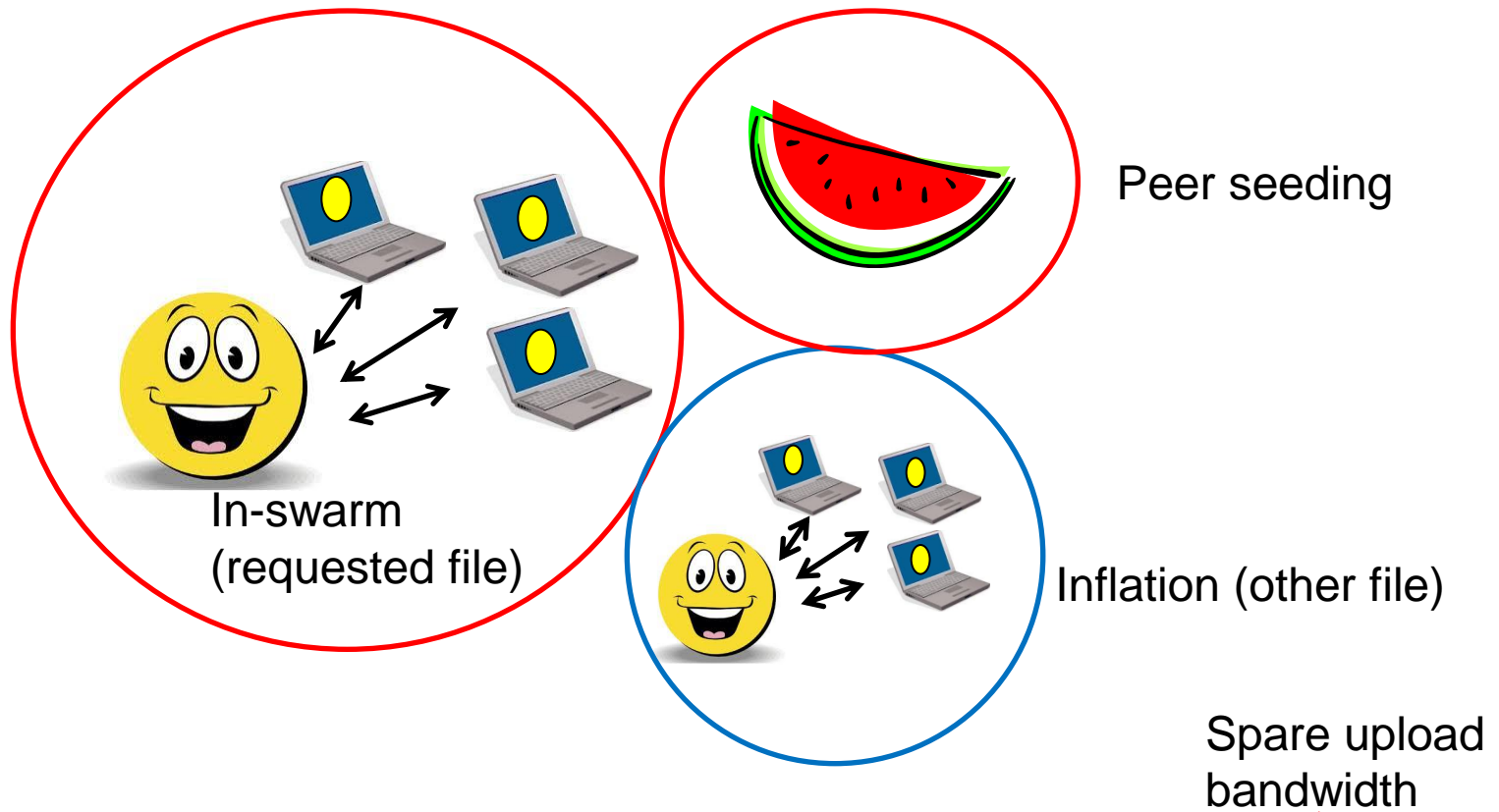
Peer upload bandwidth



$$\sum_{i \in N} \phi_i L + \sum_{i \in N} B_i^p \leq \sum_{i \in N} \lambda_i (UT - L)$$



Peer upload bandwidth

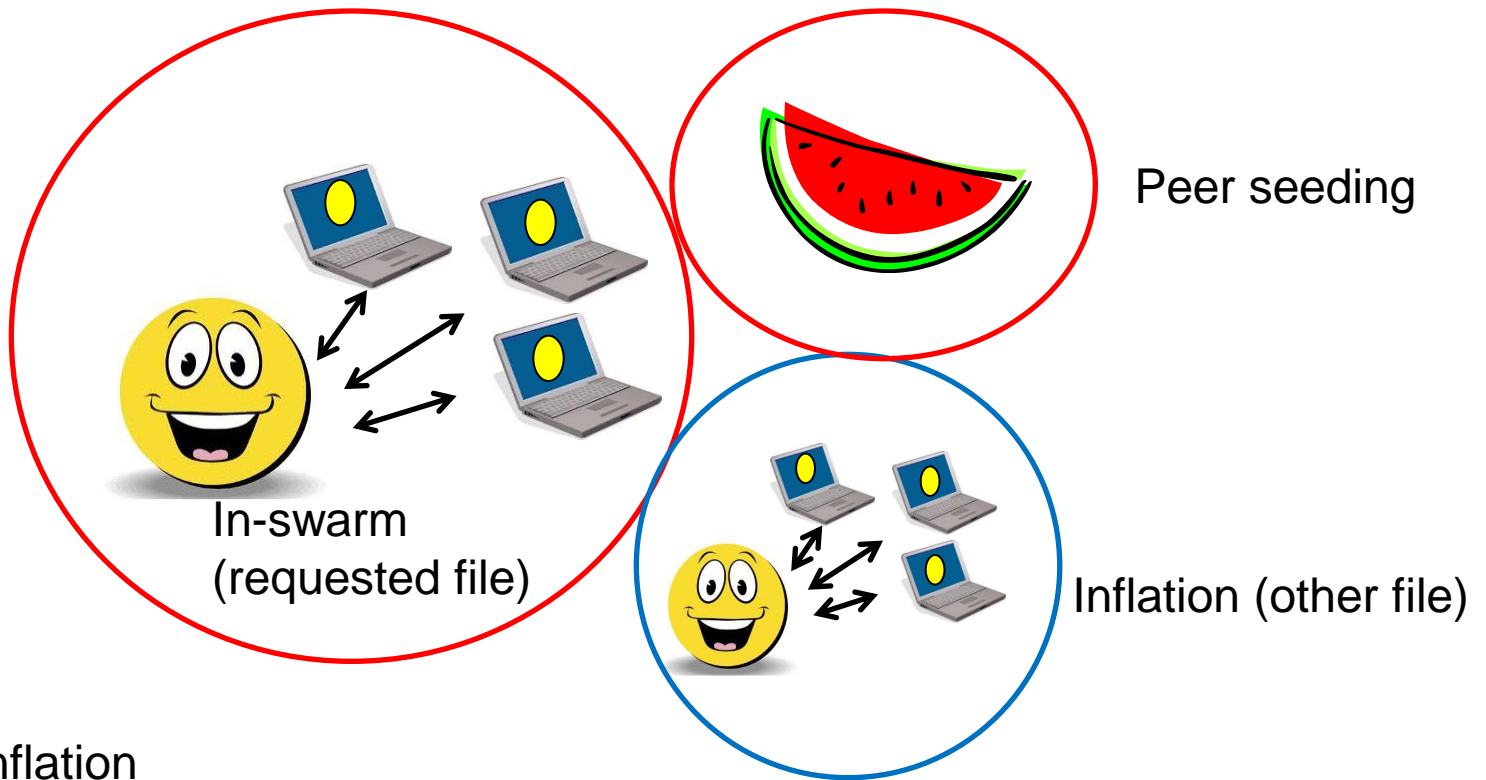


$$\sum_{i \in N} \phi_i L + \sum_{i \in N} B_i^p \leq \sum_{i \in N} \lambda_i (UT - L)$$



Just det att kalle
får marken själ
dugarna med sig
den paltbrödem
det finns en lada
och det finns en
som blanda riktat
u mäsom
EKEN
ENINU
OZUDET
MÖBELDESIGN
ward
SQUIS AKAT DÉBAT!!
Por jaginte p
odford's daughter
P * K N P *
P * P *
Avez-vous
P *
minni sko ej
fter vad hon
en vad hon
- Rell teori och va
- AHA rät
- Offentlig rät
- AHA rät, skade
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Peer upload bandwidth



Inflation contributions

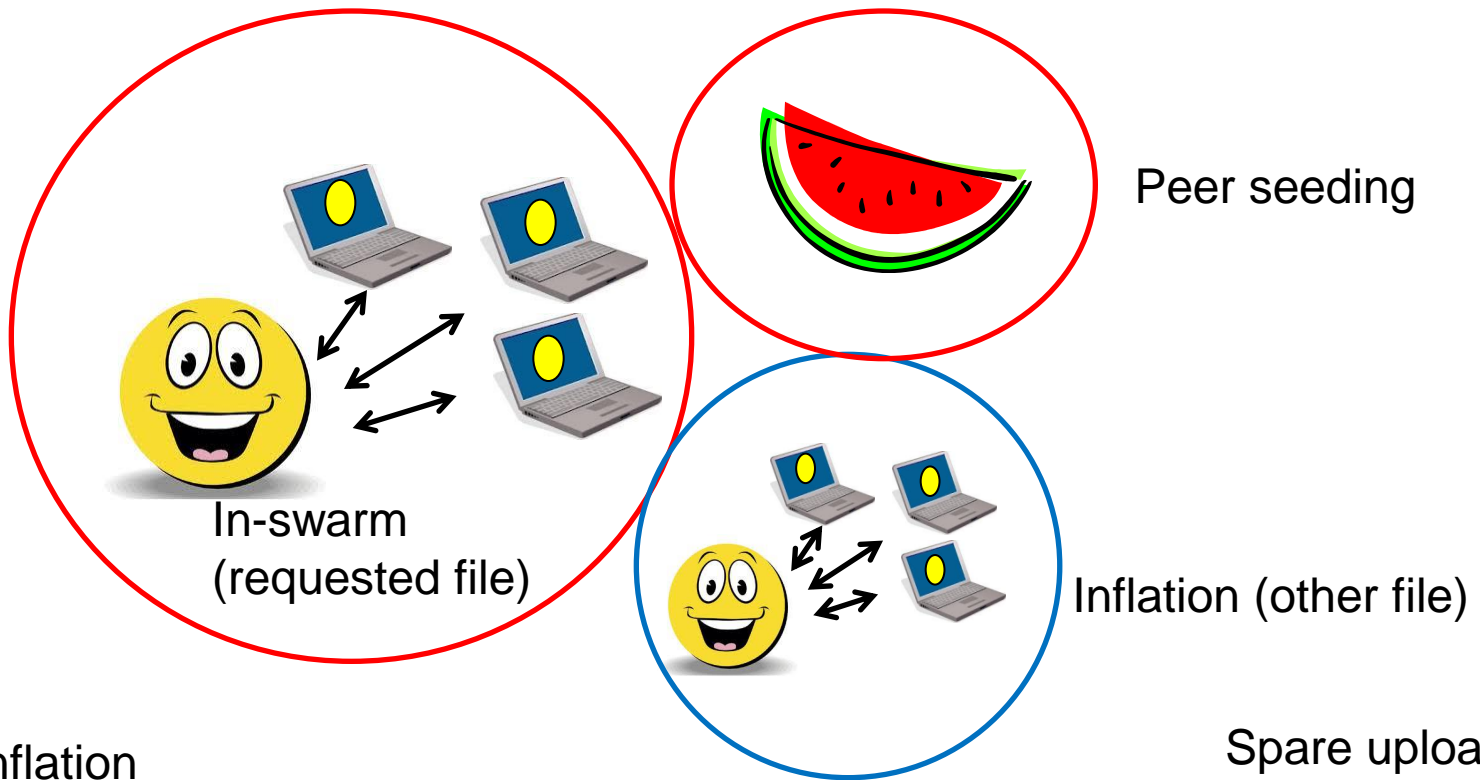
Peer seeding

$$\sum_{i \in N} \phi_i L + \sum_{i \in N} B_i^p \leq \sum_{i \in N} \lambda_i (UT - L)$$



Just det att kalle
får marke sja
dugarna med sja
den paltbrödem
det frunc on lada
och det frunc m
som blanta riefat
w masonu
ECKEN
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SQUIS AHAT DEEAT!!
Por jaginte p
odford's daughter
P * K N P x
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fater vad hon
en vad hon
- Kell teor och ra
- AHA crätt
- Offentlig rätt
- Atal crätt, skade
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Peer upload bandwidth



Inflation contributions

Peer seeding

Spare upload bandwidth

$$\sum_{i \in N} \phi_i L + \sum_{i \in N} B_i^p \leq \sum_{i \in N} \lambda_i (UT - L)$$

Just det att kalle
 får marke
 dugarna med s
 den paltbröden
 det finns en lada
 Och det finns m
 som blanda r
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 Por jag inte p

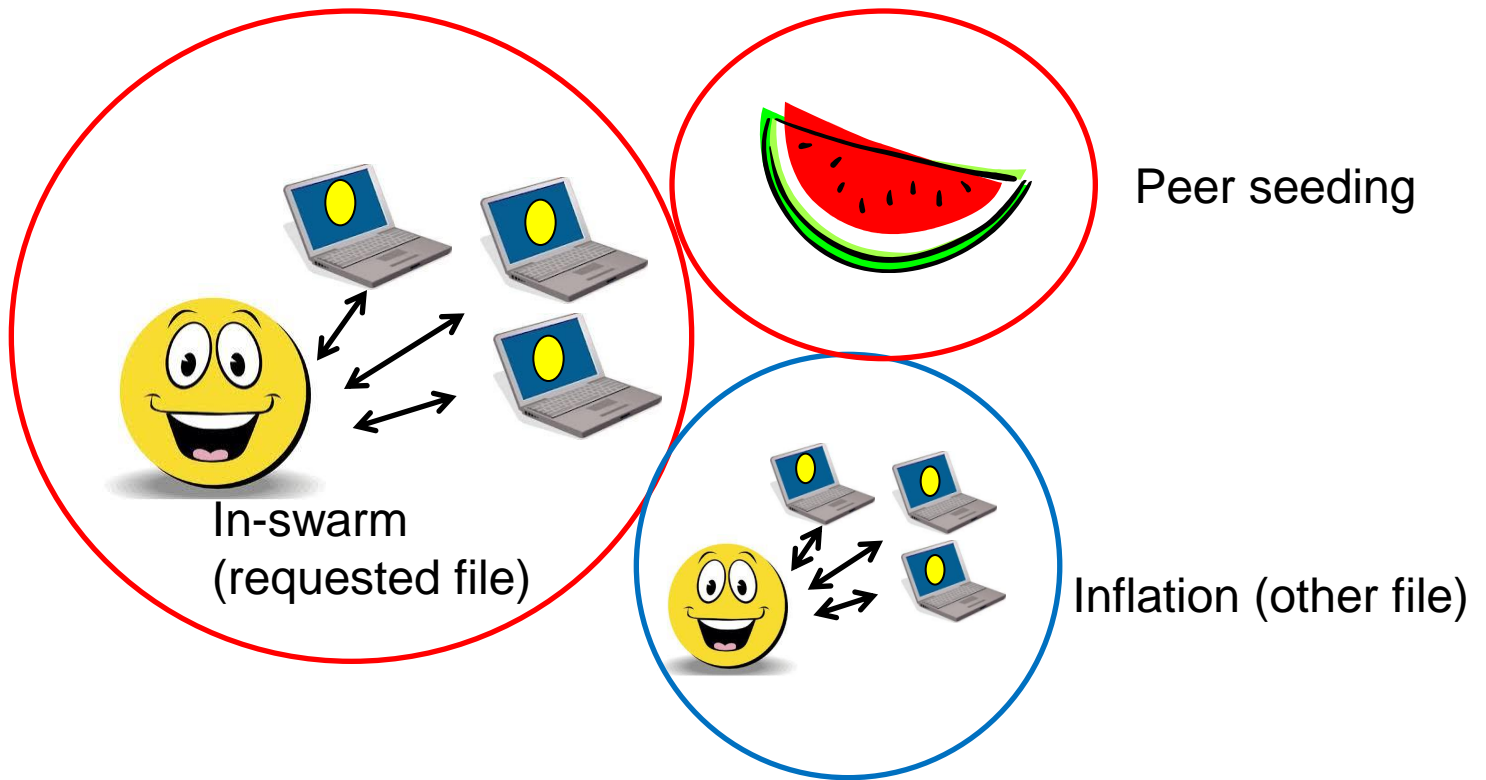
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 ter vad hon
 en vad hon

- Kell teor och r
 - AHA r rät
 - Offentlig rät
 - AHA r rät

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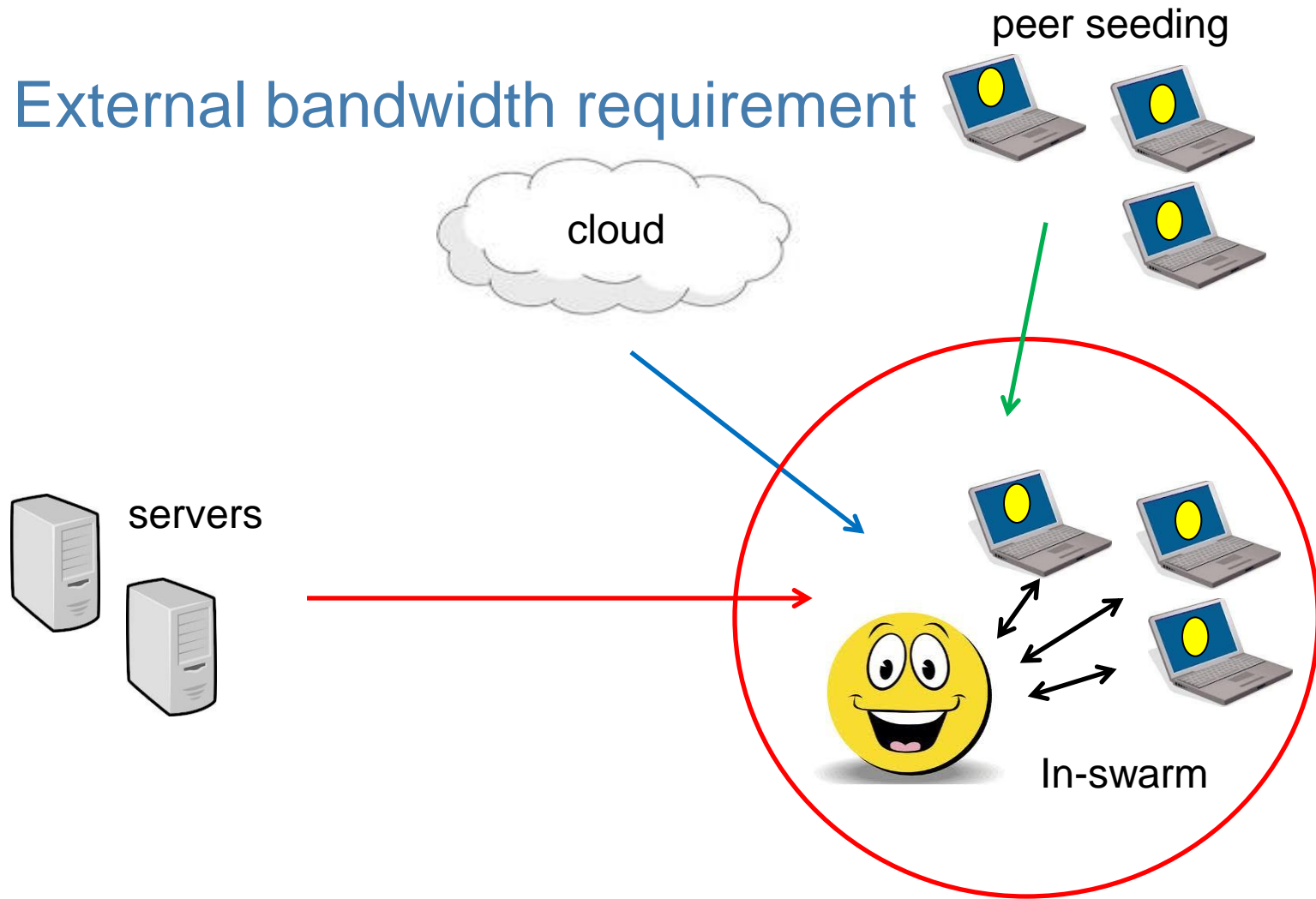
Peer upload bandwidth



$$\sum_{i \in N} \phi_i L + \sum_{i \in N} B_i^p \leq \sum_{i \in N} \lambda_i (UT - L)$$



External bandwidth requirement



Just det att kiale
fär marken själ
dugarna med sif
den paltbrödem
det frunc on lada
Och det frunc m
som blanta riefat
w masonu

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wards
SQUIS AKAT DEBAT!!
Por jaginte p

odford's daughter

BT x KN P x
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Avez-vous

minni sko ej
fter vad hon
en vad hon

- Rätt teori och r
- Åtalsrätt
- Offentlig rätt
- Åtalsrätt, skade

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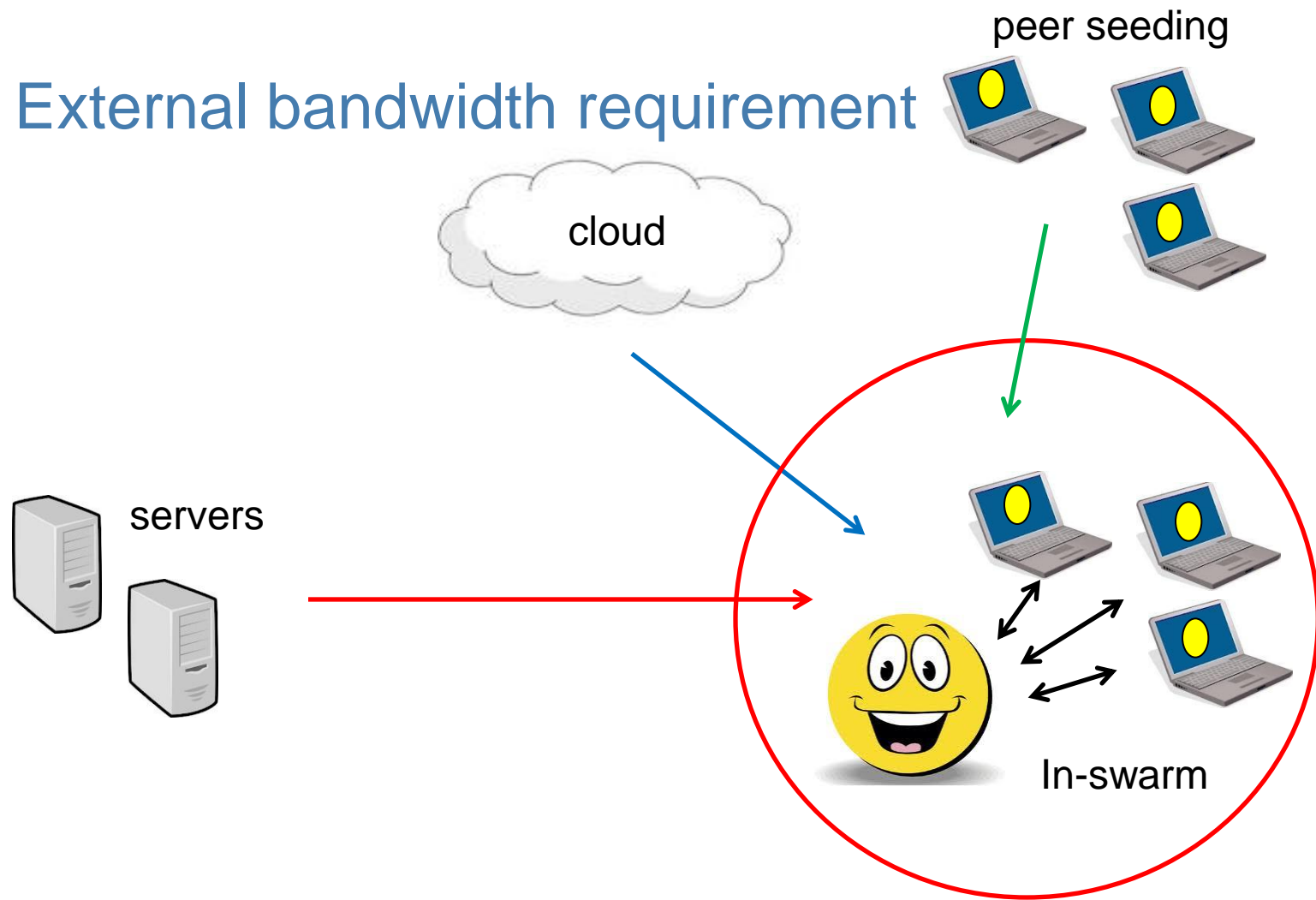
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External bandwidth requirement



$$B(\lambda_i + \phi_i) \leq B_i^s + \sum_{j \in P_i} B_{ij}^c + B_i^p$$

Just det att kiale
fär marcken själ
dingarna med sif
den paltbrödem
det frunc on lada
Och det frunc m
som blanta riefat
w masonu

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Por juginte p

odford's daughter

DP x KN P x
P x P x Avez-vous

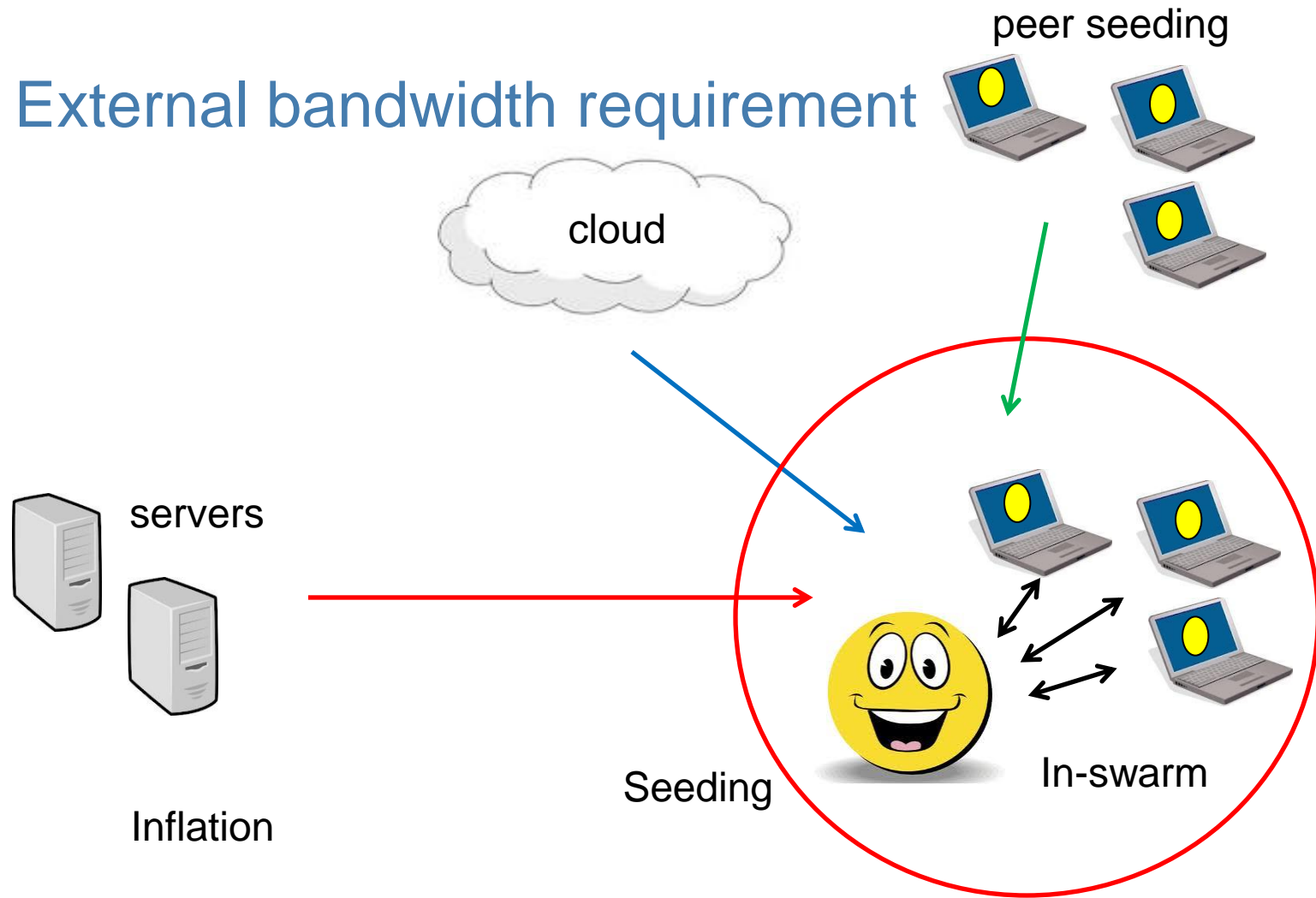
minni sko ej
fter vad hon
en vad hon

- Kell teori och va
- Aftär rätt
- Offentlig rätt
- Aftär rätt, skade

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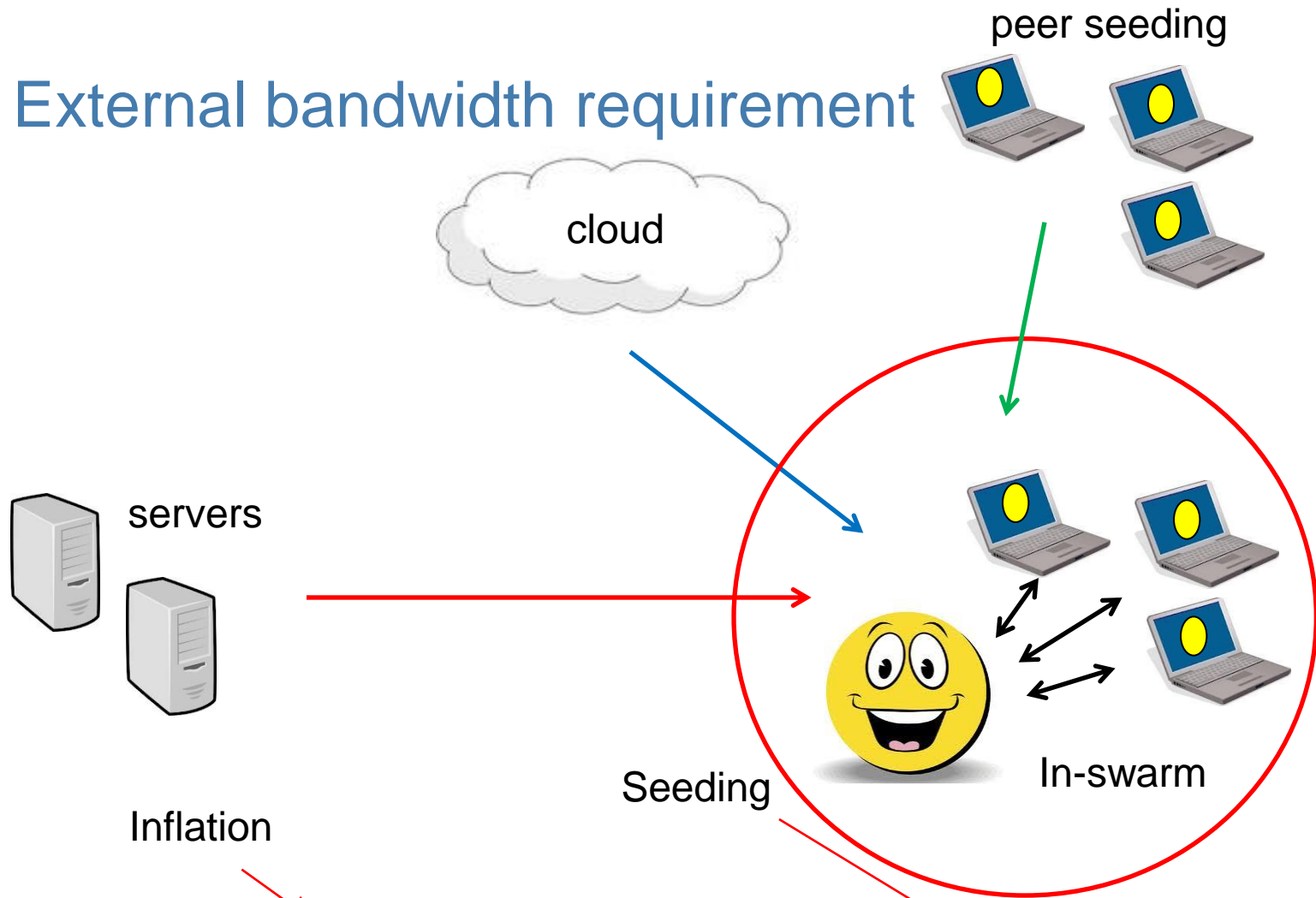
External bandwidth requirement



$$B(\lambda_i + \phi_i) \leq B_i^s + \sum_{j \in P_i} B_{ij}^c + B_i^p$$



External bandwidth requirement



$$B(\lambda_i + \phi_i) \leq B_i^s + \sum_{j \in P_i} B_{ij}^c + B_i^p$$

Just det att kiale
fär marcken sjä
dugarna med s
den paltbrödem
det frunc on lada
Och det frunc m
som blanta riefat
w masonu

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ENINU
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wards
SQUIS AHAT DÉBÉAT!!
Por jucinte p

odford's daughter

DP x KN P x
P x P x Avez-vous

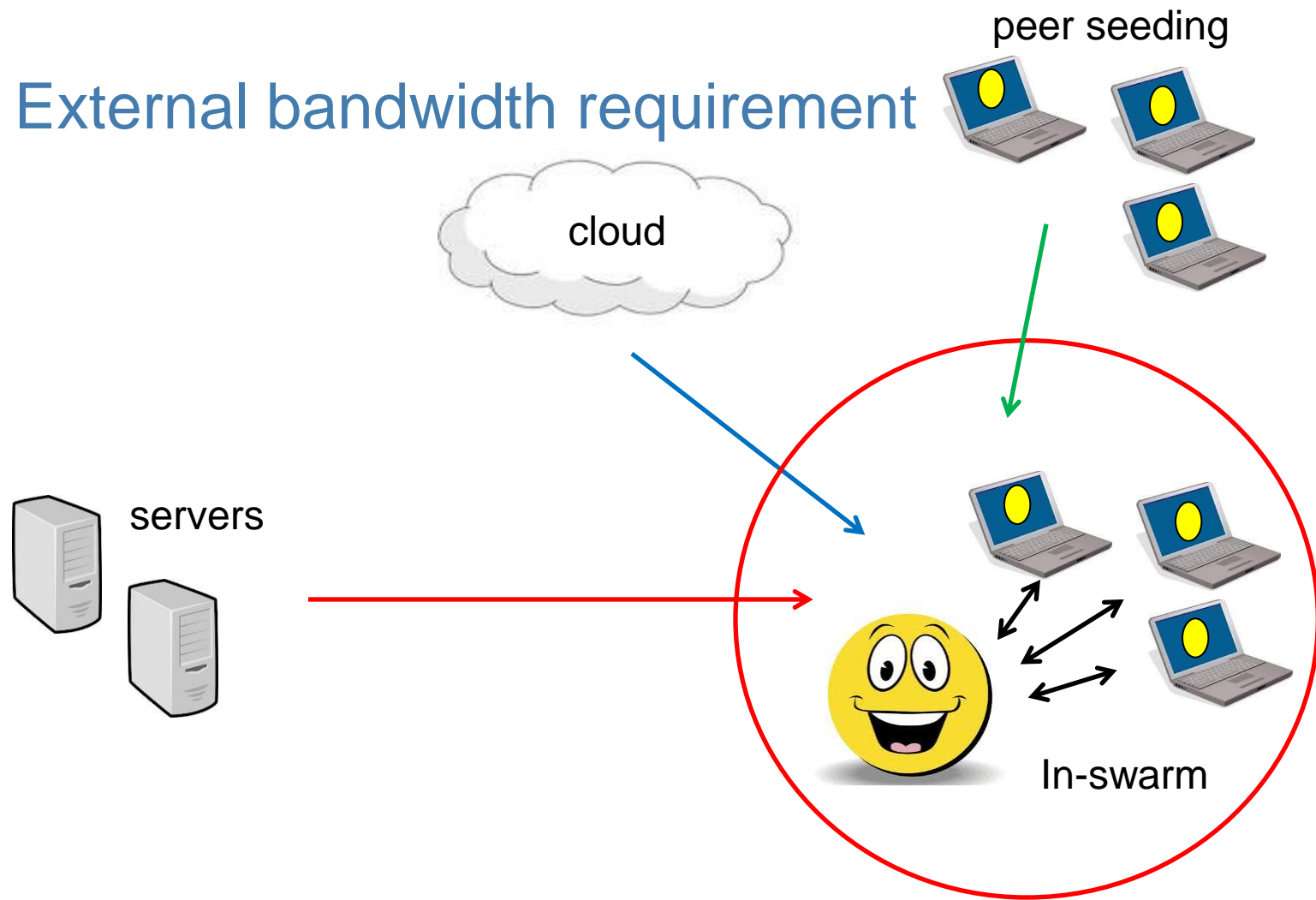
minni sko ej
fter vad hon
en vad hon

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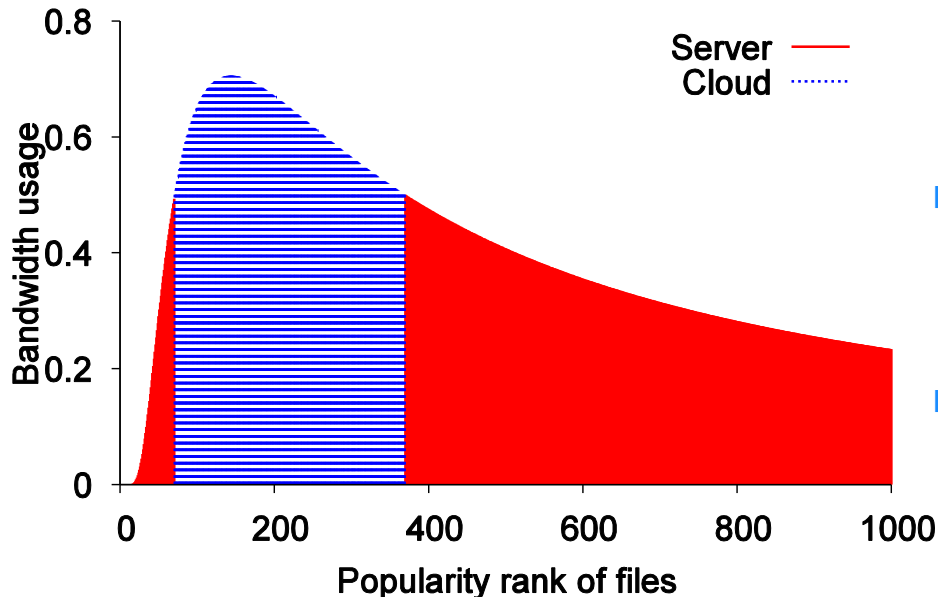
External bandwidth requirement



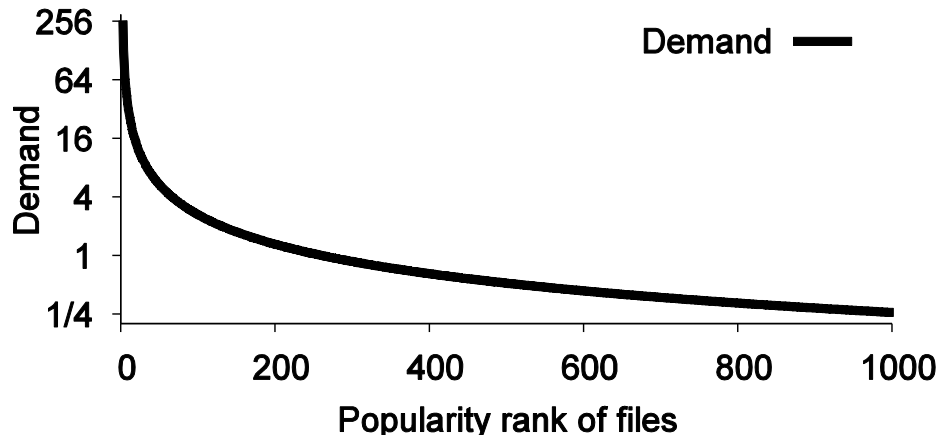
$$B(\lambda_i + \phi_i) \leq B_i^s + \sum_{j \in P_i} B_{ij}^c + B_i^p$$

Just det att kiale
fär marcken själ
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Och det frunc m
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SQUIS AKAT DÉREAT!!
Por jaginte p
mofford's daughter
AY x KN x
AY x
männi sko ej
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en vad hon
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- Atal crätt, skade
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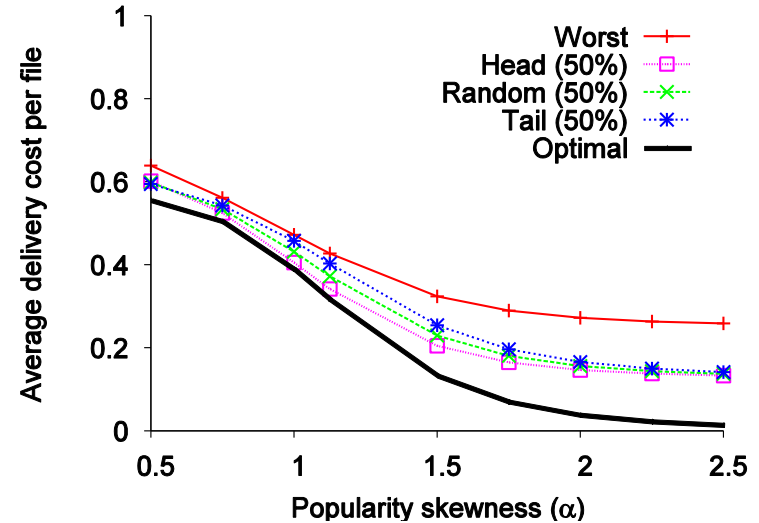
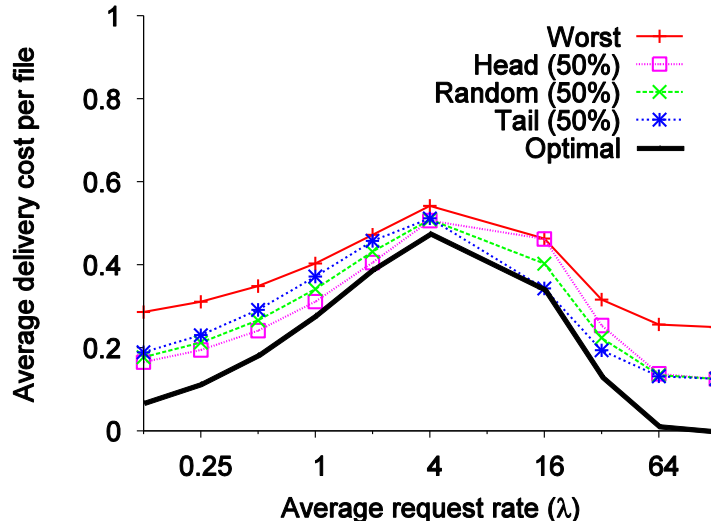
No seeding or bundling (UT=L)



- Example allocation for optimal policy (when no seeding or bundling)
- Intermediately popular files pushed to the cloud

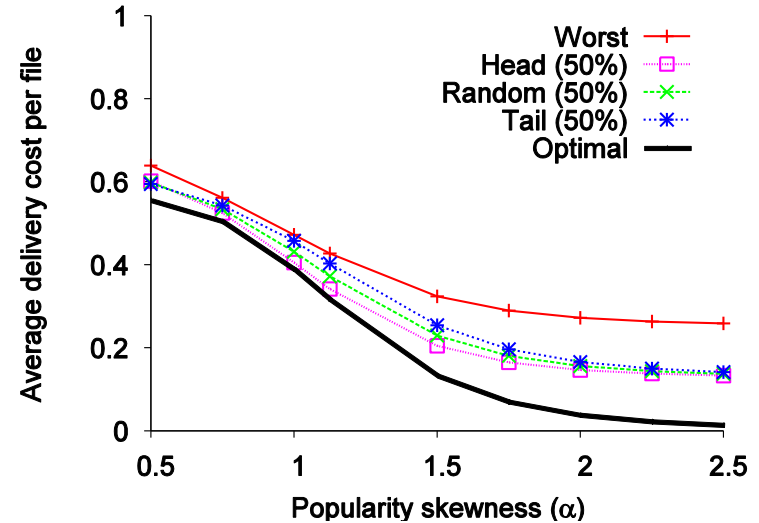
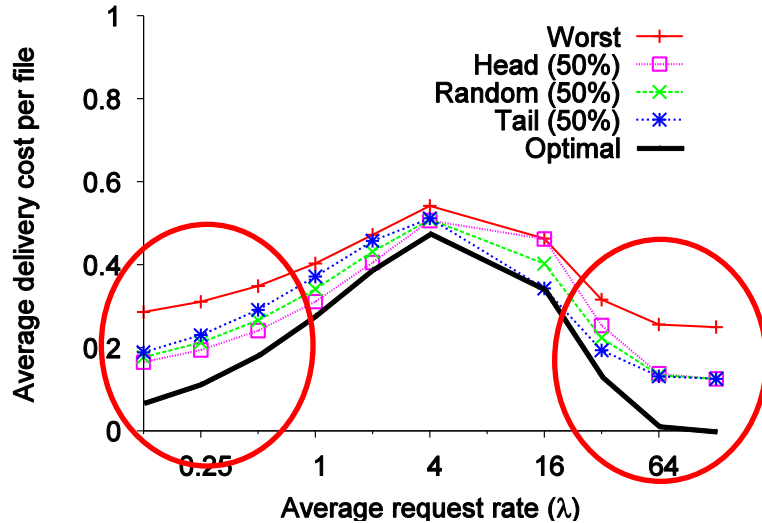


No seeding or bundling (UT=L)



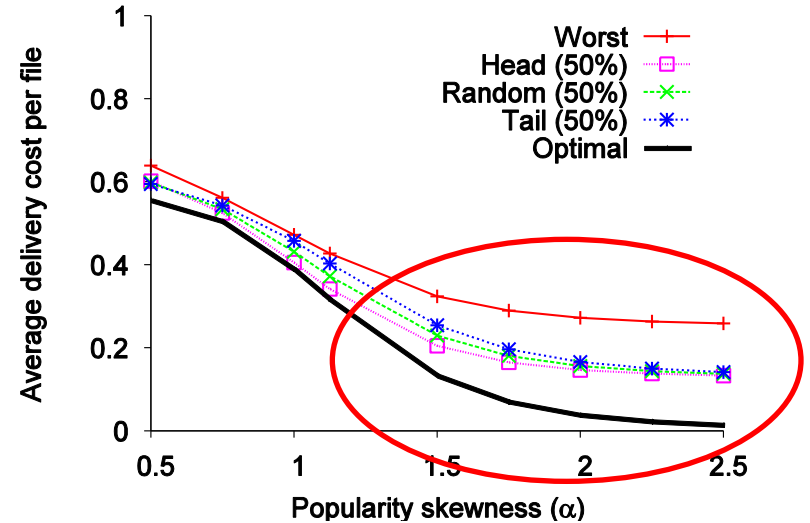
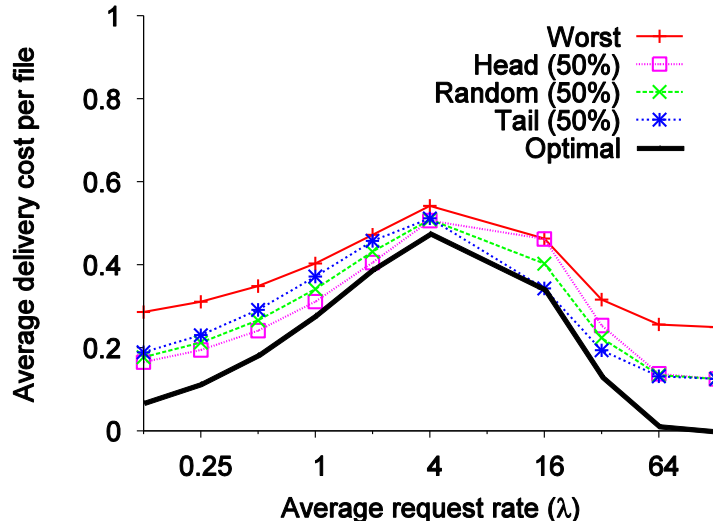
- Policy comparison (which files to push to cloud)
 - Optimal (intermediate) vs. baseline policies
- Big differences when either
 - High/low load
 - High popularity skew
- Catalogue size has little impact (not shown)

No seeding or bundling (UT=L)



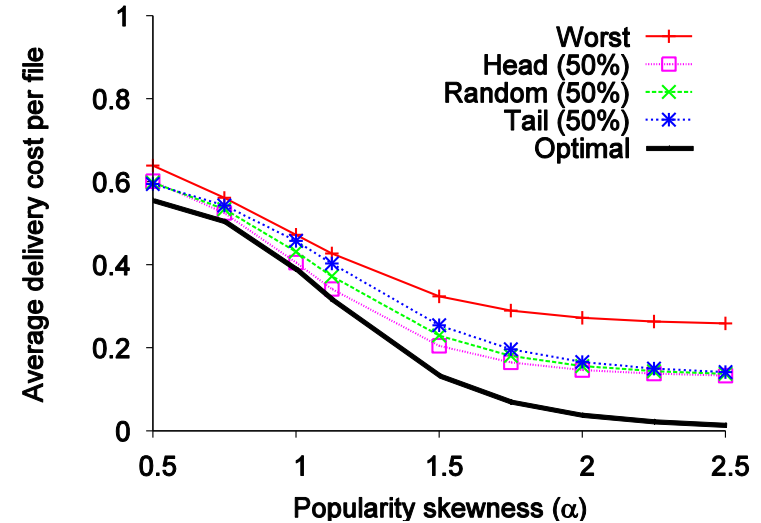
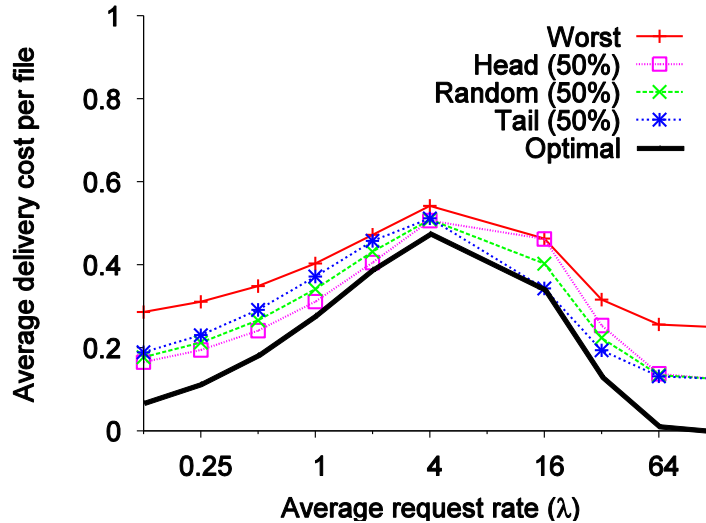
- Policy comparison (which files to push to cloud)
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No seeding or bundling (UT=L)



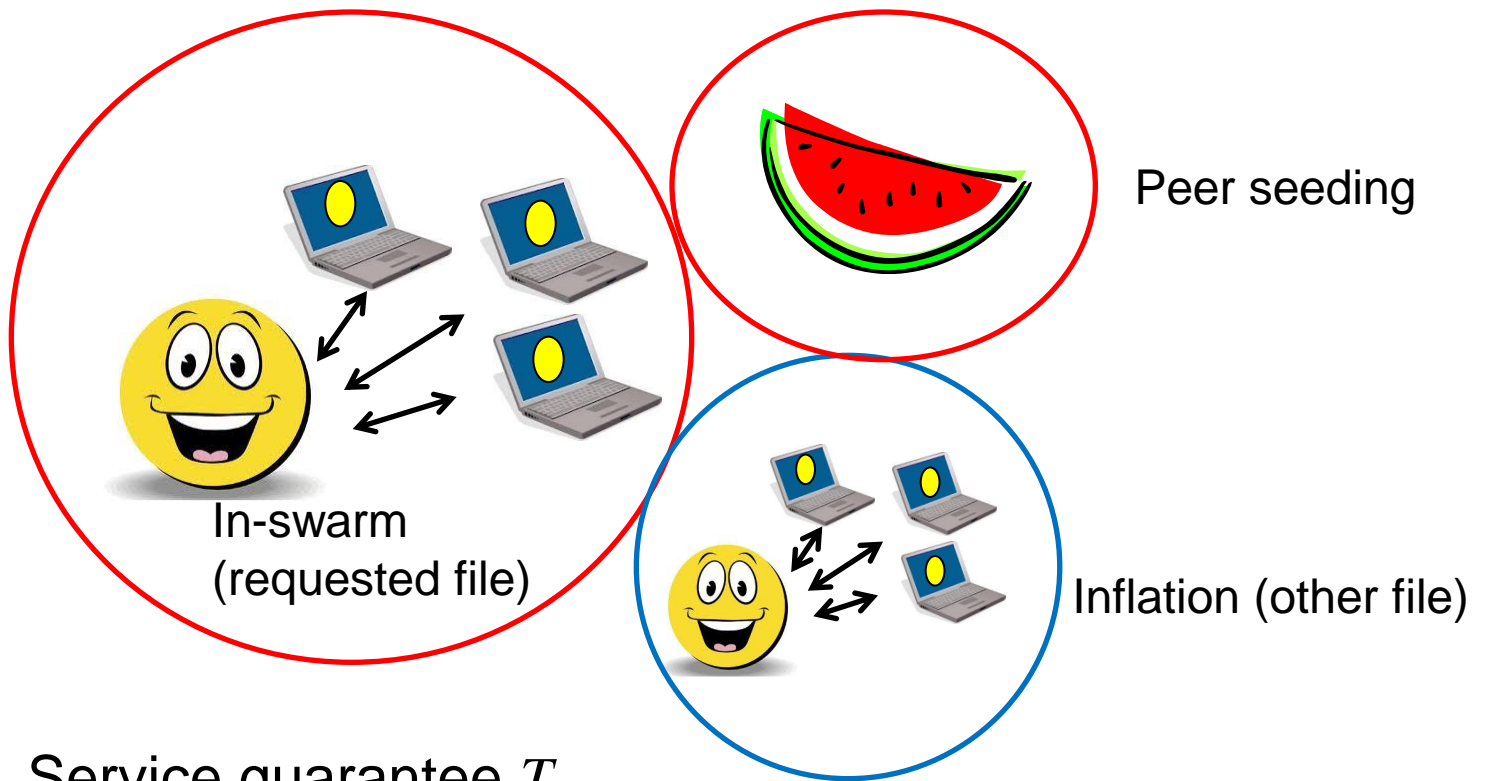
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No seeding or bundling (UT=L)



- Policy comparison (which files to push to cloud)
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- Big differences when either
 - High/low load
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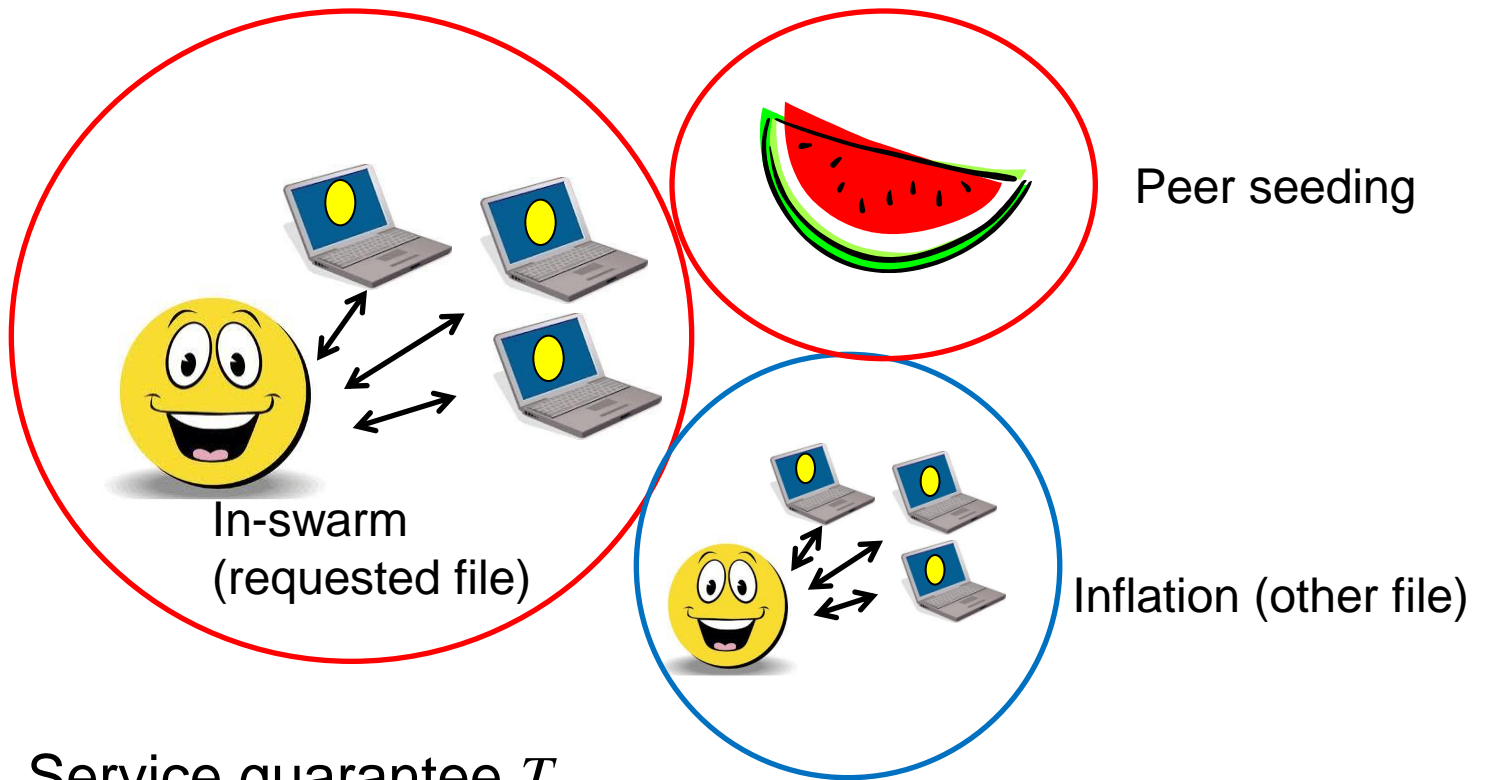
Peer upload bandwidth



- Service guarantee T
- Help out, but **only** during download/service



Peer upload bandwidth



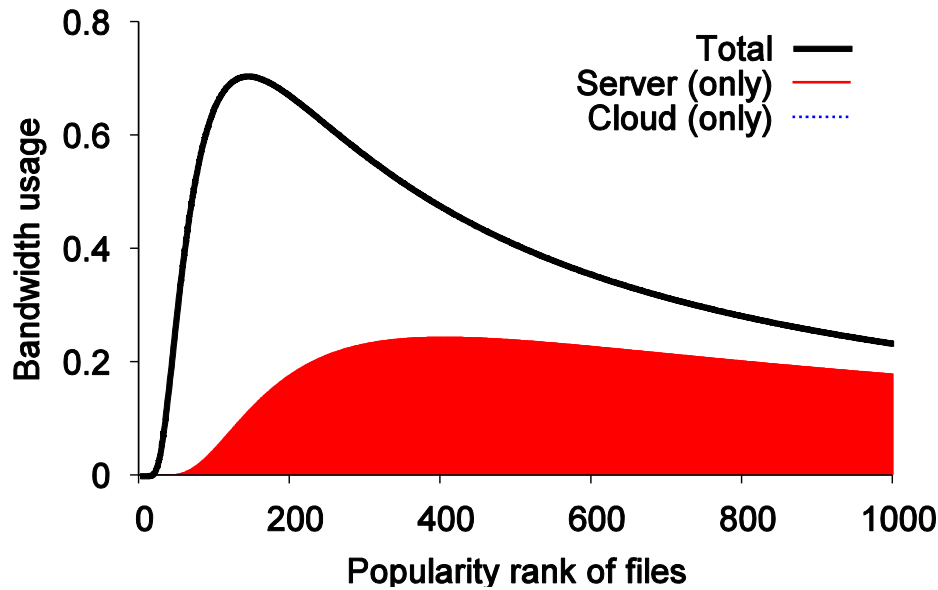
- Service guarantee T
- Help out, but **only** during download/service

How to best use this bandwidth?

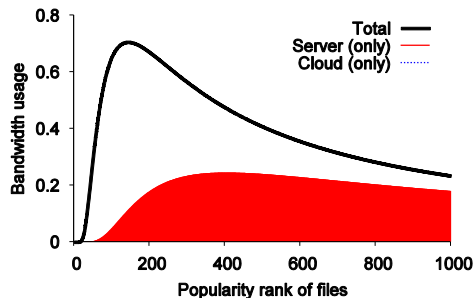


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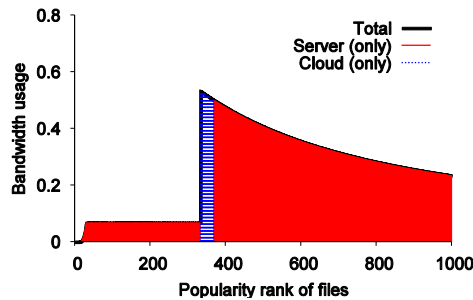
Seeding only (UT > L)



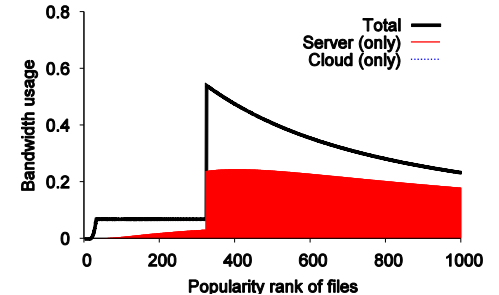
■ Help less popular



Seeding (only)



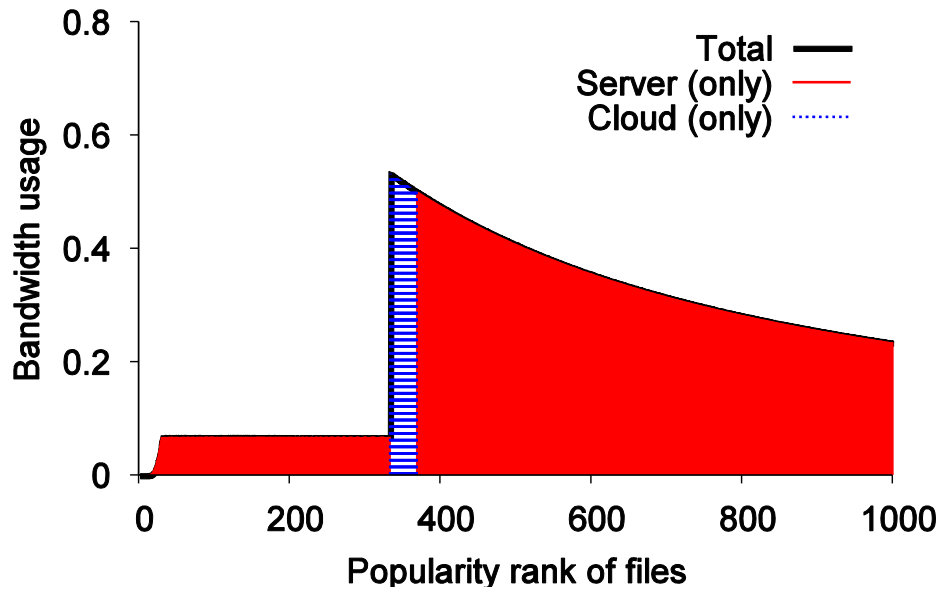
Bundling (only)



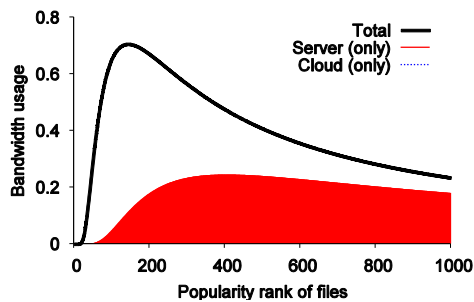
Hybrid



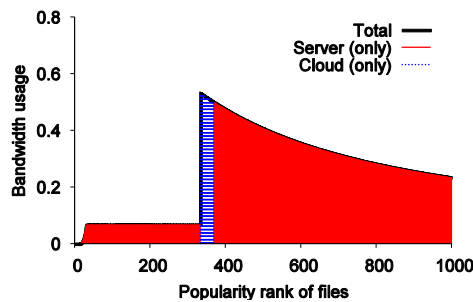
Bundling only (UT > L)



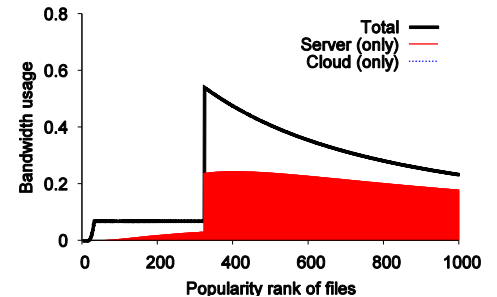
- Inflate most popular
- Intermediate to cloud



Seeding (only)



Bundling (only)

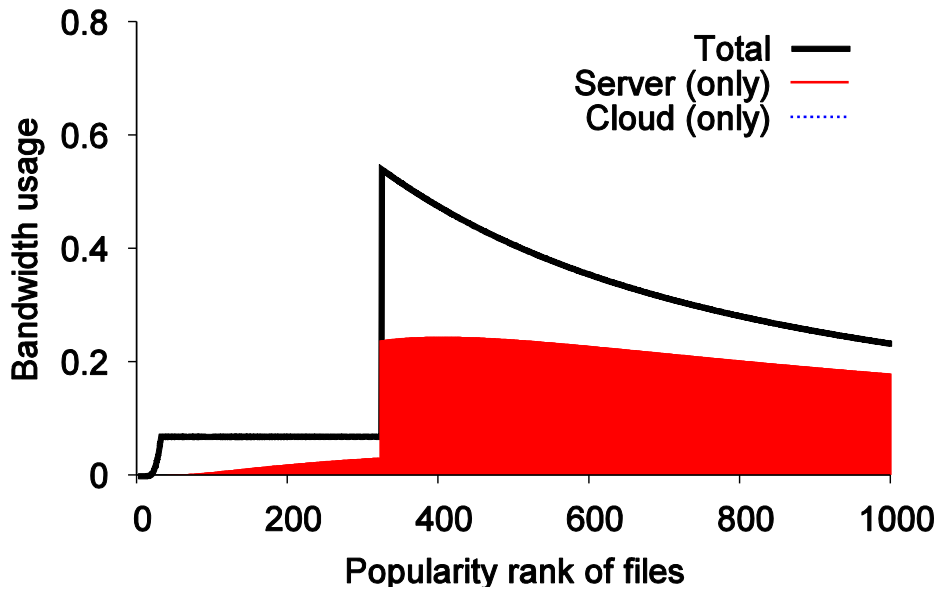


Hybrid

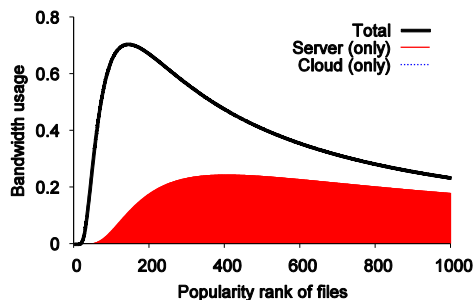
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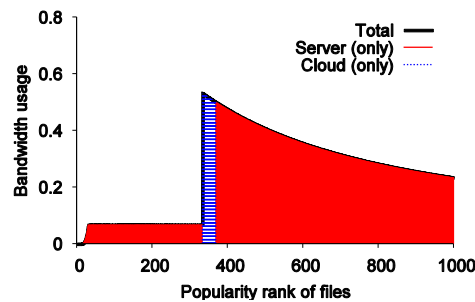
Hybrid (UT > L)



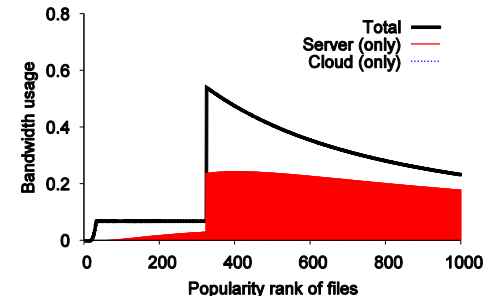
- Inflate most popular
- Depends less on cloud



Seeding (only)



Bundling (only)



Hybrid

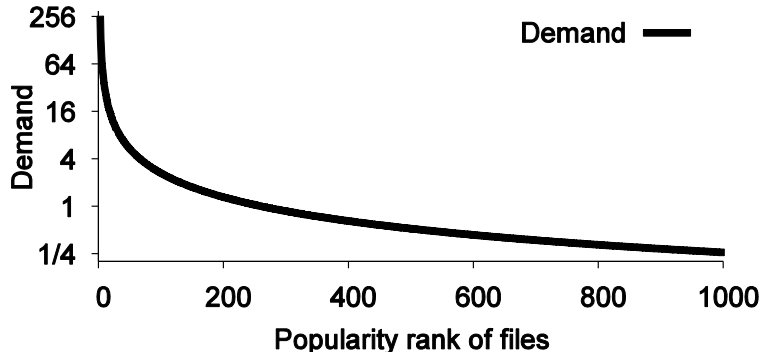


Policy comparison

- How did we decide which files to “inflate”?
- Baseline inflation policies with different complexity
 - Proportional: $\phi_i \propto \lambda_i$ (based on random peer interest, to help friends, for example)
 - Random: $\phi_i \propto 1$ (same for all)
 - Basic: yes/no decision using base allocation; same to all
 - Fine: Greedy search (with “basic” as starting point)
 - Other baseline inflation policies [IFIP Networking ‘10]



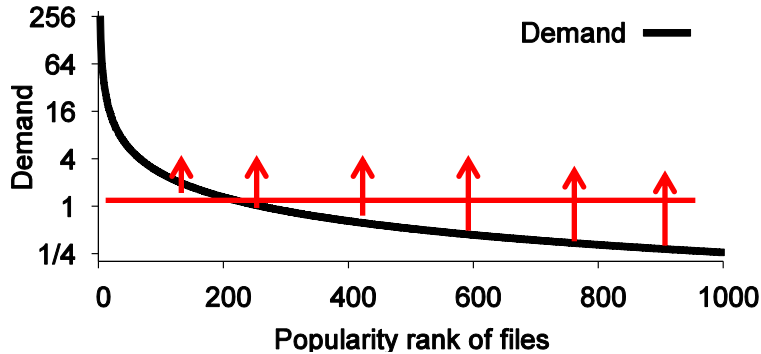
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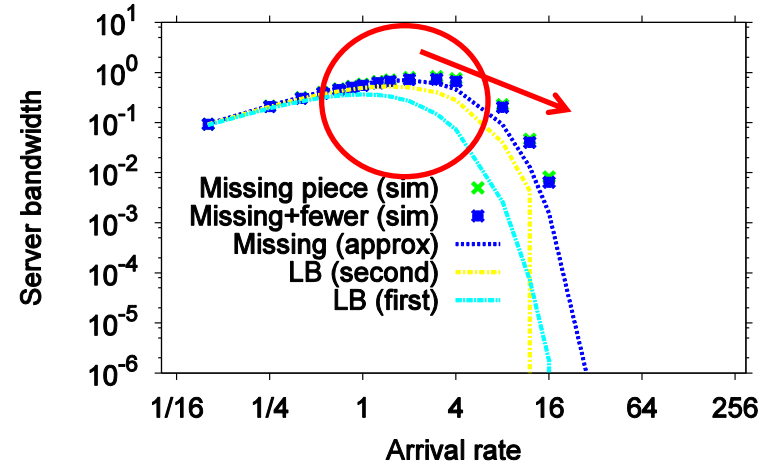
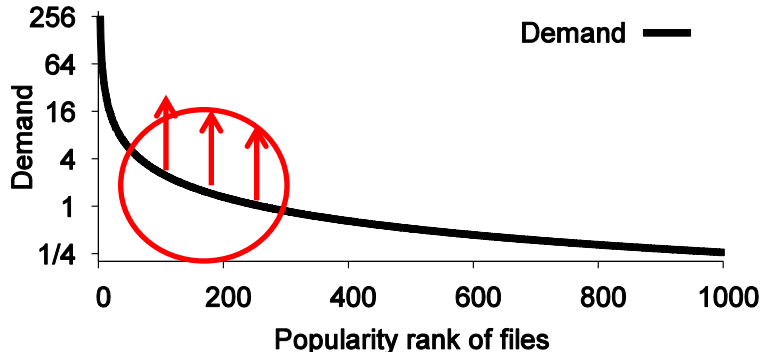
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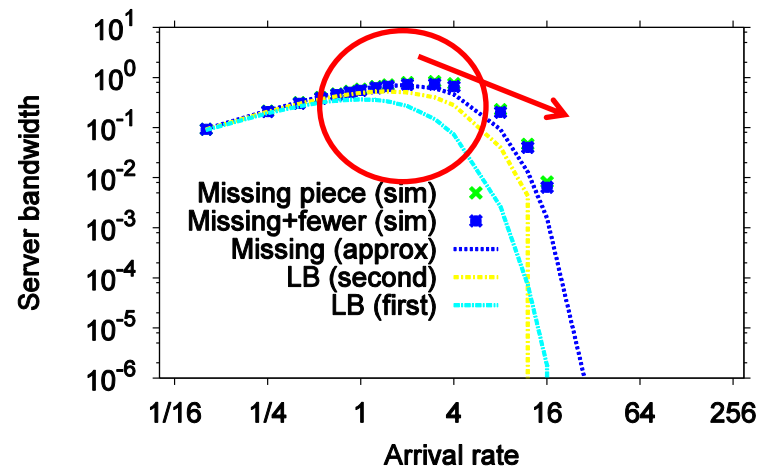
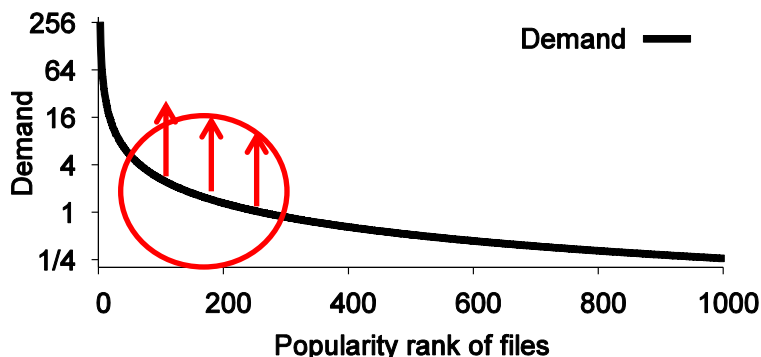
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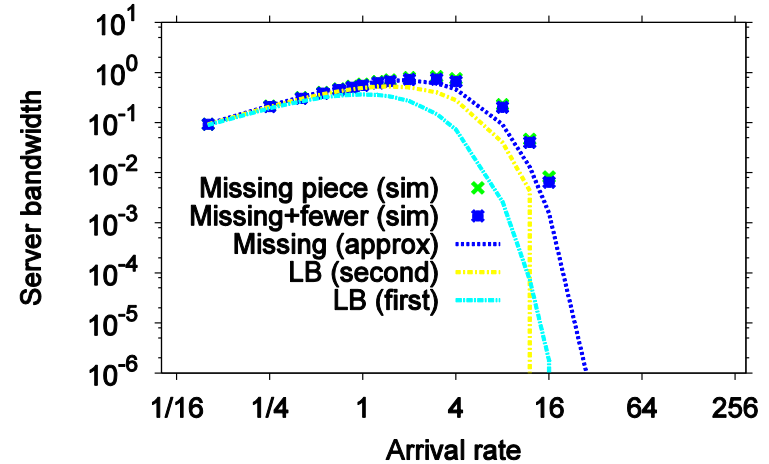
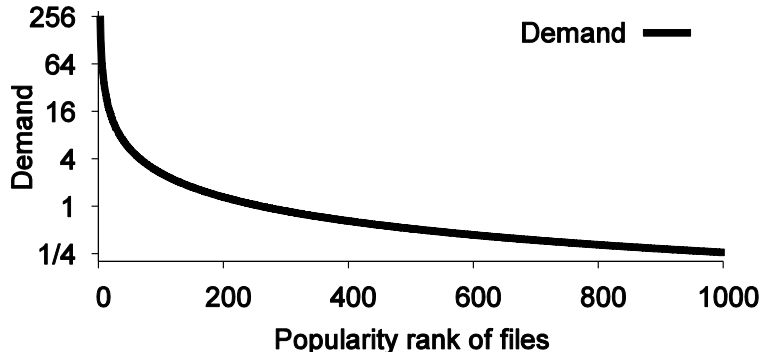
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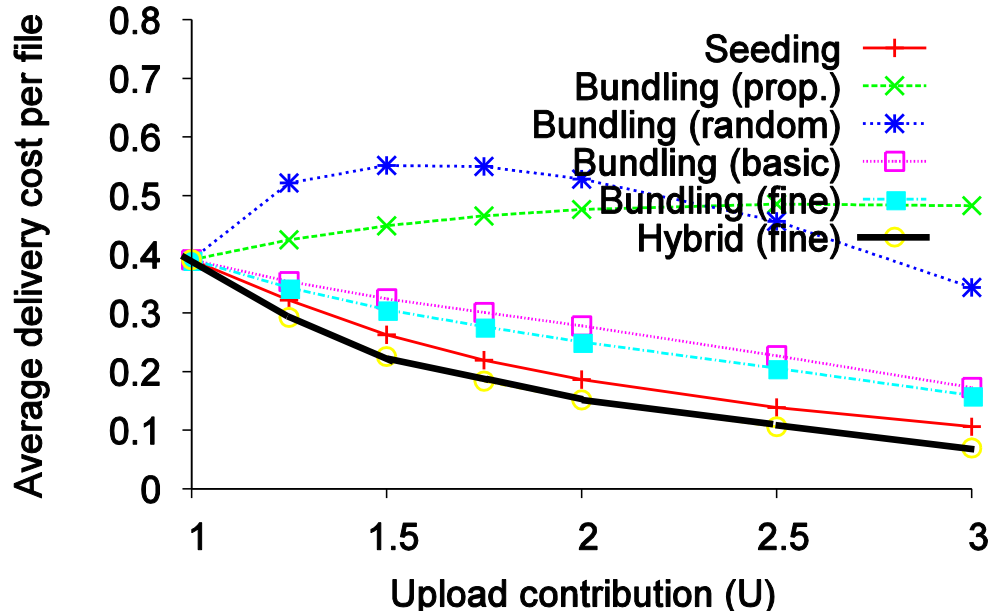
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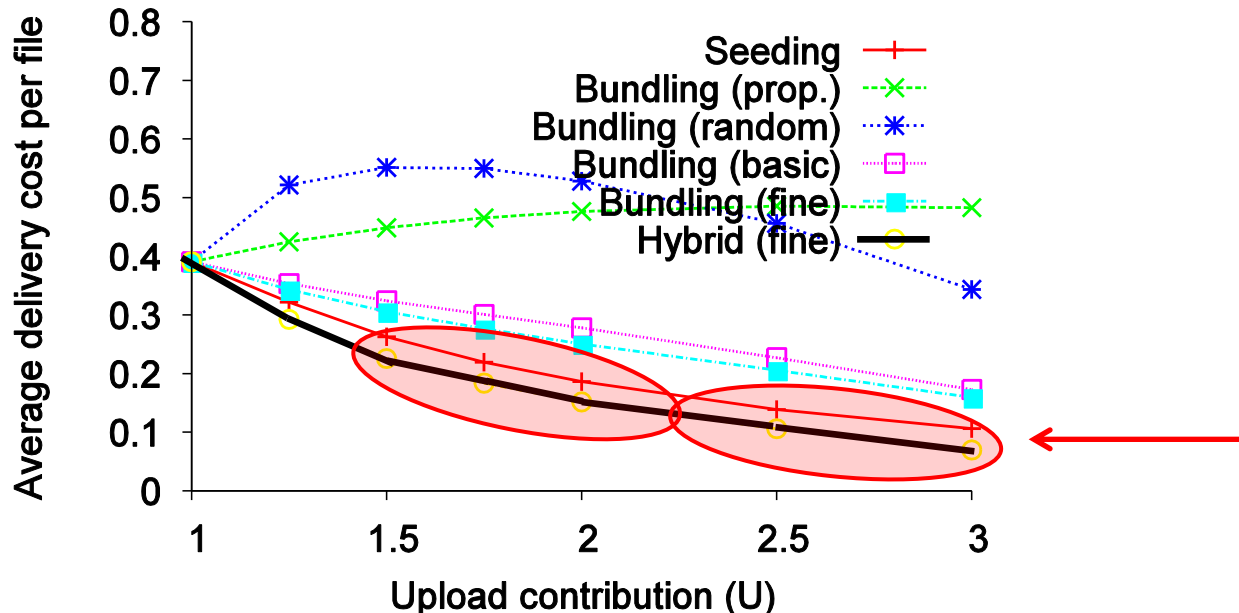
Policy comparison



- Baseline inflation policies with different complexity
 - Up to 20% benefit using hybrid approach
 - Reckless use of bundling can be costly
 - Simpler (basic) policies achieves most of the benefits



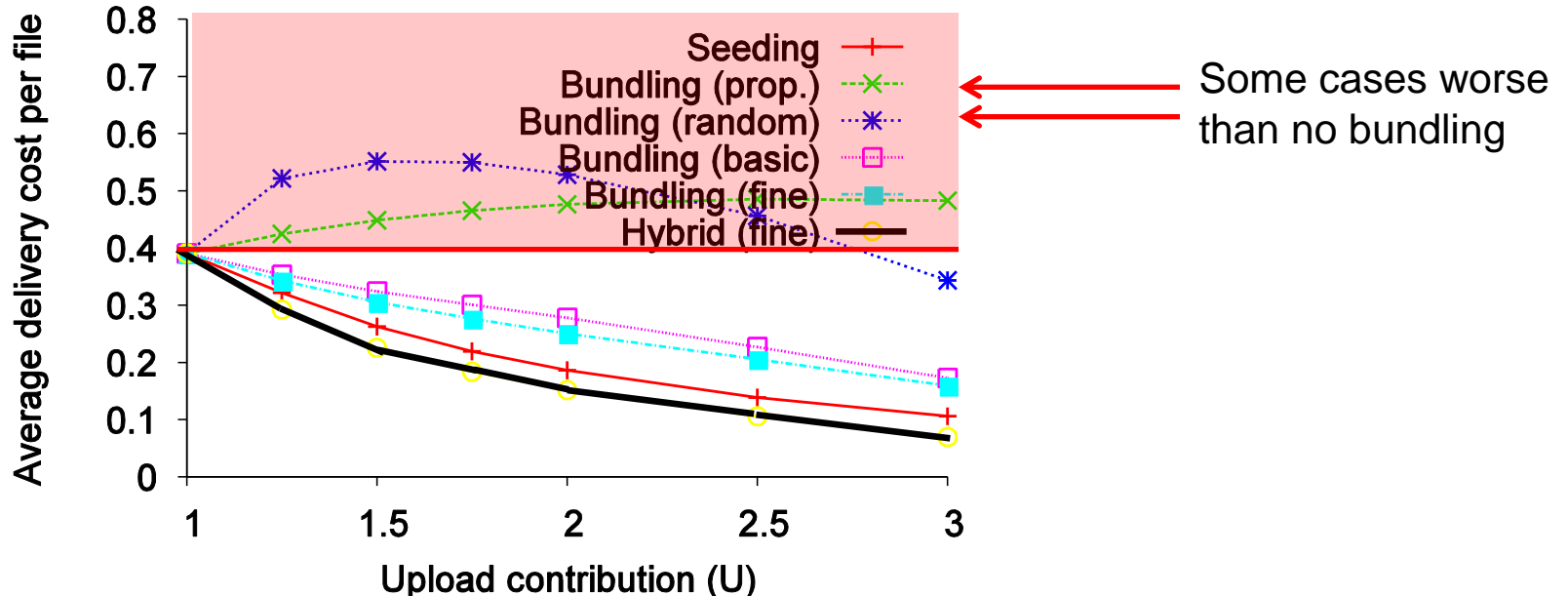
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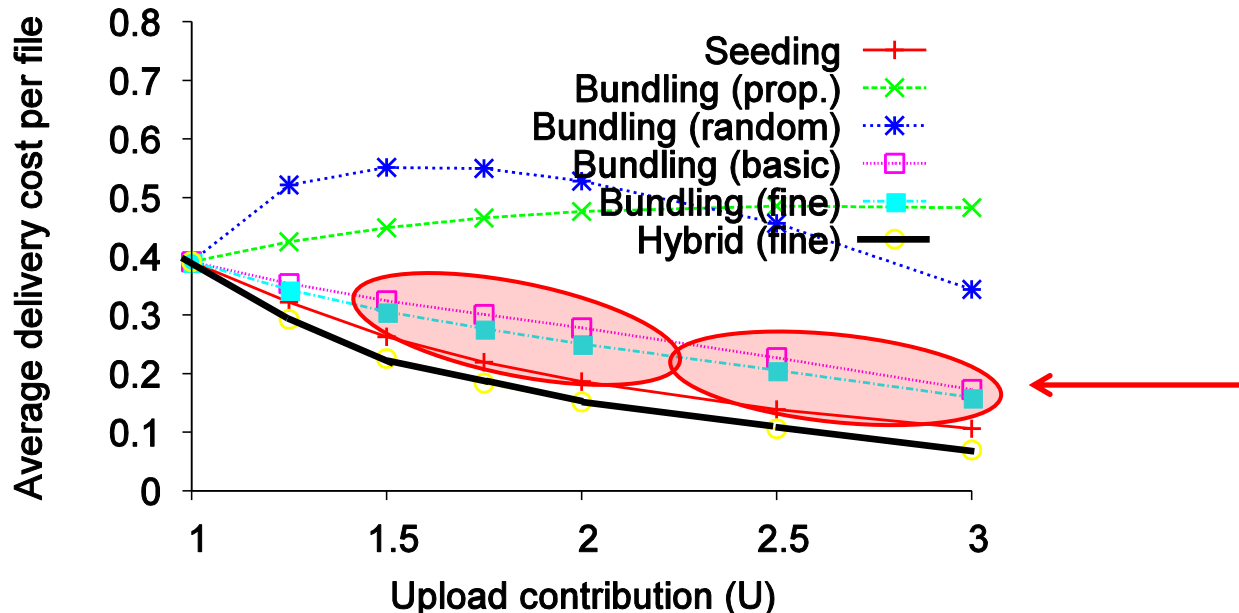
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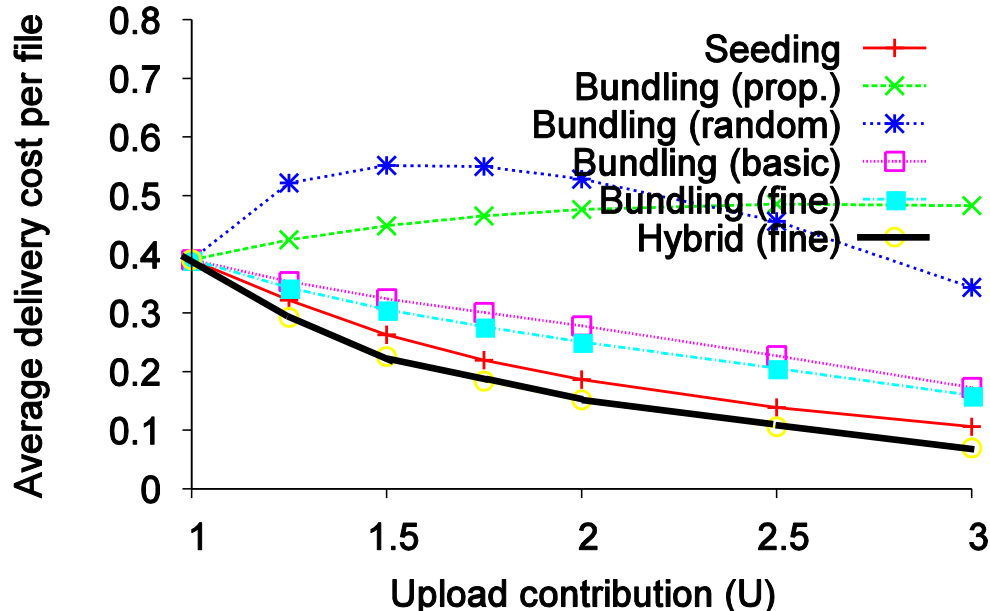
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Contributions

- Derive and evaluate bounds and approximations of the minimum server bandwidth required to ensure target average download rate
- Compare simple policy classes for which content to push to the cloud and provide insights regarding the importance of careful content selection
- Compare the best usage of the peer upload bandwidth, including policies determining how seeding and torrent inflation should be best utilized
- Also (in paper):
 - Where to direct clients in systems where the cloud provider has a differentiated cost model and charges based on the locality of the clients that are served



Thank you!

- Niklas Carlsson Linköping University
- György Dan KTH Royal Institute of Technology
- Derek Eager University of Saskatchewan
- Anirban Mahanti NICTA

