Co-evolution of Content Popularity and Delivery in Mobile P2P Networks

Srinivasan Venkatramanan and Anurag Kumar

Department of ECE,
Indian Institute of Science,
Bangalore 560 012.
vsrini,anurag@ece.iisc.ernet.in

March 26, 2012
Outline

1 Motivation

2 System Model

3 Fluid limits

4 Optimization Problems

5 Concluding Remarks
Outline

1 Motivation
2 System Model
3 Fluid limits
4 Optimization Problems
5 Concluding Remarks
A scalable approach to content delivery for mobile nodes
Mobile P2P Networks

- A scalable approach to content delivery for mobile nodes
- Why Mobile P2P?
  - Increased penetration of smart phones
Mobile P2P Networks

- A scalable approach to content delivery for mobile nodes
- Why Mobile P2P?
  - Increased penetration of smart phones
  - Growing demand for high-bandwidth content on mobile devices
Mobile P2P Networks

- A scalable approach to content delivery for mobile nodes
- Why Mobile P2P?
  - Increased penetration of smart phones
  - Growing demand for high-bandwidth content on mobile devices
  - A single item of content (news, ringtone, etc.) may be of interest to several users in a region
Mobile P2P Networks

- A scalable approach to content delivery for mobile nodes
- Why Mobile P2P?
  - Increased penetration of smart phones
  - Growing demand for high-bandwidth content on mobile devices
  - A single item of content (news, ringtone, etc.) may be of interest to several users in a region
- Can be studied under the Mobile Opportunistic Networks paradigm
Example setup: Highlights of Infocom Keynote Speech
Example setup: Highlights of Infocom Keynote Speech

Figure: Mobile P2P Network - An Example

- Popularity broadcast by central server
- Currently 100 people want the video
- Poisson meeting between mobiles (possible file transfer)

Colors:
- Red: want the video
- Green: have the video
Evolution of Content Popularity

- Creators: Increase the popularity of the content

2. Chandramani Singh, Anurag Kumar, Rajesh Sundaresan and Eitan Altman, “Optimal Forwarding in Delay Tolerant Networks with Multiple Destinations”, WiOpt 2011
Evolution of Content Popularity

- Creators: Increase the popularity of the content \(^1\)
- Distributors: Optimally control delivery mechanisms \(^2\)

\(^1\)David Kempe, Jon Kleinberg and Éva Tardos, “Maximizing the Spread of Influence in a Social Network”, In Proceedings of KDD 2003

\(^2\)Chandramani Singh, Anurag Kumar, Rajesh Sundaresan and Eitan Altman, “Optimal Forwarding in Delay Tolerant Networks with Multiple Destinations”, WiOpt 2011
Evolution of Content Popularity

- Creators: Increase the popularity of the content \(^1\)
- Distributors: Optimally control delivery mechanisms \(^2\)
- Influence spread models (from viral marketing) can be employed

---

\(^1\)David Kempe, Jon Kleinberg and Éva Tardos, “Maximizing the Spread of Influence in a Social Network”, In Proceedings of KDD 2003

\(^2\)Chandramani Singh, Anurag Kumar, Rajesh Sundaresan and Eitan Altman, “Optimal Forwarding in Delay Tolerant Networks with Multiple Destinations”, WiOpt 2011
Our Contributions

- Set up Markov models for the co-evolution of content popularity and delivery.
- Derive ODE limits (uid limits) from the Markov models.
- Show that the popularity evolution model under study is equivalent to the SIR epidemic model.
- Use the uid limits to solve various optimization problems for both the content creator and the content distributor.

V. Srinivasan (IISc, Bangalore)
Our Contributions

- Set up Markov models for the co-evolution of content popularity and delivery
Our Contributions

- Set up Markov models for the co-evolution of content popularity and delivery
- Derive o.d.e. limits (*fluid limits*) from the Markov models
Our Contributions

- Set up Markov models for the co-evolution of content popularity and delivery
- Derive o.d.e. limits (fluid limits) from the Markov models
- Show that the popularity evolution model under study, is equivalent to the SIR epidemic model
Our Contributions

- Set up Markov models for the co-evolution of content popularity and delivery
- Derive o.d.e. limits (fluid limits) from the Markov models
- Show that the popularity evolution model under study, is equivalent to the SIR epidemic model
- Use the fluid limits to solve various optimization problems for both the content creator and the content distributor
Outline

1. Motivation
2. System Model
3. Fluid limits
4. Optimization Problems
5. Concluding Remarks
System Model

Spread of *single* item of content among a homogeneous population of mobile *nodes*
System Model

Spread of single item of content among a homogeneous population of mobile nodes

![Diagram](image)

**Figure:** Various states and the transitions in the Co-evolution model
System Model

Spread of *single* item of content among a homogeneous population of mobile *nodes*.

**Figure:** Various states and the transitions in the Co-evolution model.

Central server to broadcast popularity information at regular intervals.
Network setup for Popularity

Homogeneous Influence Linear Threshold model (HILT Model)\(^3\)

\[ \gamma_N = \frac{\Gamma}{N-1}, \Gamma \leq 1 \]

\[ \Theta_i \sim F \]

\[ \gamma_N \]

\(i\)

Figure: HILT Model

\(^3\)David Kempe, Jon Kleinberg and Éva Tardos, “Maximizing the Spread of Influence in a Social Network”, In Proceedings of KDD 2003
Network setup for Popularity

Homogeneous Influence Linear Threshold model (HILT Model)\(^3\)

\[
\gamma_N = \frac{\Gamma}{N-1}, \quad \Gamma \leq 1
\]

\[\Theta_i \sim F, \quad i \in N\]

\(\gamma_N = \frac{\Gamma}{N-1}, \quad \Gamma \leq 1\)

Figure: HILT Model

- Complete network on \(\mathcal{N}\), \(N = |\mathcal{N}|\)

---

\(^3\)David Kempe, Jon Kleinberg and Éva Tardos, “Maximizing the Spread of Influence in a Social Network”, In Proceedings of KDD 2003
Network setup for Popularity

Homogeneous Influence Linear Threshold model (HILT Model)\(^3\)

\[ \gamma_N = \frac{\Gamma}{N-1}, \quad \Gamma \leq 1 \]

\[ \Theta_i \sim F_{\gamma_N i} \]

Figure: HILT Model

- Complete network on \( \mathcal{N} \), \( N = |\mathcal{N}| \)
- Influence edge weights \( \gamma_N = \frac{\Gamma}{N-1} \)

---

\(^3\)David Kempe, Jon Kleinberg and Éva Tardos,“Maximizing the Spread of Influence in a Social Network”, In Proceedings of KDD 2003
Network setup for Popularity

Homogeneous Influence Linear Threshold model (HILT Model)\(^3\)

\[ \gamma_N = \frac{\Gamma}{N-1}, \Gamma \leq 1 \]

\[ \Theta_i \sim F, i \in N \]

Figure: HILT Model

- Complete network on \(N, N = |N|\)
- Influence edge weights \(\gamma_N = \frac{\Gamma}{N-1}\)
- Random threshold \(\Theta_i \sim F, i \in N\)

\(^3\)David Kempe, Jon Kleinberg and Éva Tardos, “Maximizing the Spread of Influence in a Social Network”, In Proceedings of KDD 2003
A relay $j \notin A(k - 1)$ becomes a destination at time $k$, if

$$\gamma_N |A(k - 1)| \geq \Theta_j$$
Content Spread (SI model)

Relays

\[ \text{want} = 0 \\
\text{have} = 0 \]

\[ S(k) \setminus Y(k) \]

\[ Y(k) \]

\[ A(k) \setminus X(k) \]

Destinations

\[ \text{want} = 1 \\
\text{have} = 1 \]

[Graph showing the flow between relays and destinations with various states of want and have]

Possible destination copy
Possible relay copy

Popularity updates

Each pair of destinations meet at points of a Poisson process with rate \( \lambda \). Possible destination copy:

\[ i \in A(k) \setminus X(k) \text{ meets } j \in X(k) \cup Y(k) \]

Copy occurs with probability \( \alpha \).

Possible relay copy:

\[ i \in S(k) \setminus Y(k) \text{ meets } j \in X(k) \cup Y(k) \]

Copy occurs with probability \( \sigma \).
Content Spread (SI model)

Each pair of nodes meet at points of a Poisson process with rate $\lambda_N$

- **Possible destination copy**: $i \in A(k) \setminus \mathcal{X}(k)$ meets $j \in \mathcal{X}(k) \cup \mathcal{Y}(k)$
  - Copy occurs with probability $\alpha$

- **Possible relay copy**: $i \in S(k) \setminus \mathcal{Y}(k)$ meets $j \in \mathcal{X}(k) \cup \mathcal{Y}(k)$
  - Copy occurs with probability $\sigma$
Outline

1. Motivation
2. System Model
3. Fluid limits
4. Optimization Problems
5. Concluding Remarks
HILT model

\[ \Theta_i \sim F \]

\[ \gamma_N = \frac{\Gamma}{N-1}, \Gamma \leq 1 \]

\[ A(k) = |A(k)|, \quad D(k) = |D(k)|, \quad B(k) = |B(k)| \]

Kurtz theorem 4: Convergence of Markov chains to their unique limits

---

\[ \text{V. Srinivasan (IISc, Bangalore)} \]
The HILT model

\[ \gamma_N \sim F \]

\[ \gamma_N = \frac{\Gamma}{N-1}, \Gamma \leq 1 \]

Let \( A(k) = |A(k)|, D(k) = |D(k)| \) and \( B(k) = |B(k)| \)

\[ A(k-1) = B(k) \]

\[ A(k) \]

\[ A(U) \]

---

HILT model

\[ \gamma_N = \frac{\Gamma}{N-1}, \gamma \leq 1 \]

\[ \Theta_i \sim F \]

\[ \gamma_N = \frac{\Gamma}{N-1}, \gamma \leq 1 \]

- Let \( A(k) = |A(k)|, D(k) = |D(k)| \) and \( B(k) = |B(k)| \)
- \((B(k), D(k))\) is a Markov chain
- Kurtz theorem \(^4\): Convergence of Markov chains to their fluid limits

Scaling and Drift Equations

Scaled Markov process \((B^N(t), D^N(t))\) evolving over mini-slots

\[
\begin{align*}
(B^N(t + 1), D^N(t + 1)) \\
(B^N(t), D^N(t))
\end{align*}
\]

\[
\begin{align*}
(B(k), D(k)) & \quad \frac{1}{N} \quad (B(k + 1), D(k + 1))
\end{align*}
\]
Scaling and Drift Equations

Scaled Markov process \((B^N(t), D^N(t))\) evolving over mini-slots

\[
(B^N(t + 1), D^N(t + 1)) \\
(B^N(t), D^N(t)) \\
(B(k), D(k)) \quad \frac{1}{N} \quad (B(k + 1), D(k + 1))
\]

- Each infectious destination in \(D^N(t)\) attempts to influence the relays with probability \(\frac{1}{N}\)
  - Success: Contributes its influence of \(\frac{\Gamma}{N-1}\) and moves to \(B^N(t + 1)\)
  - Failure: Stays in the \(D^N(t + 1)\)
Scaling and Drift Equations

\[ C^N(t) = \frac{D^N(t)}{N} + Z^N_b(t + 1) \]

\[ B^N(t + 1) = B^N(t) + C^N(t) \]


Scaling and Drift Equations

\[ C^N(t) = \frac{D^N(t)}{N} + Z^N_b(t + 1) \]

\[ B^N(t + 1) = B^N(t) + C^N(t) \]

\[ D^N(t + 1) = D^N(t) + \mathbb{E} \left[ \frac{F(\gamma N(B^N(t) + C^N(t))) - F(\gamma N B^N(t))}{1 - F(\gamma N B^N(t))} \right] \times \left( N - B^N(t) - D^N(t) \right) - C^N(t) + Z^N_d(t + 1) \]
Fluid Limit for Interest Evolution - HILT Model

- Defining $\tilde{B}^N(t)$, $\tilde{C}^N(t)$ and $\tilde{D}^N(t)$ as the fractional processes, we can then state the following theorem.
Defining $\tilde{B}^N(t)$, $\tilde{C}^N(t)$ and $\tilde{D}^N(t)$ as the fractional processes, we can then state the following theorem:

**Theorem**

Given the interest evolution Markov process $(\tilde{B}^N(t), \tilde{D}^N(t))$, for the threshold distribution with density $f(\cdot)$, with bounded $f'(\cdot)$ and hazard function $h_F(x) = \frac{f(x)}{1-F(x)}$, we have for each $T > 0$ and each $\epsilon > 0$,

$$\mathbb{P}\left(\sup_{0 \leq u \leq T} \left\| (\tilde{B}^N(\lfloor Nu \rfloor), \tilde{D}^N(\lfloor Nu \rfloor)) - (b(u), d(u)) \right\| > \epsilon \right) \xrightarrow{N \to \infty} 0$$

where $(b(u), d(u))$ is the unique solution to the o.d.e.,

$$\begin{align*}
\dot{b} &= d \quad (1) \\
\dot{d} &= h_F(\Gamma b) \Gamma d (1 - b - d) - d \quad (2)
\end{align*}$$

with initial conditions $(b(0) = 0, d(0) = d_0)$. 
Uniform threshold distribution: $h_F(x) = \frac{1}{1-x}$. Let $r = 1 - \Gamma + \Gamma d_0$ then we have,
HILT Model: Effect of Threshold Distribution

- **Uniform threshold distribution**: \( h_F(x) = \frac{1}{1-x} \). Let \( r = 1 - \Gamma + \Gamma d_0 \) then we have,

\[
\begin{align*}
    b(t) &= \frac{d_0}{r} - \frac{d_0}{r} e^{-rt} \\
    d(t) &= d_0 e^{-rt}
\end{align*}
\] (3) (4)

- Exponential distribution with parameter \( \beta \): \( h_F(x) = \beta \) (memoryless). The uid limit is the solution to the o.d.e.,

\[
\dot{b} = \beta \Gamma d_0 (1 - b - d) - d
\]

This is equivalent to the SIR epidemic model with infection rate \( \beta \Gamma \) and recovery rate of 1.
HILT Model: Effect of Threshold Distribution

- **Uniform threshold distribution**: \( h_F(x) = \frac{1}{1-x} \). Let \( r = 1 - \Gamma + \Gamma d_0 \) then we have,

\[
\begin{align*}
\dot{b}(t) &= \frac{d_0}{r} - \frac{d_0}{r} e^{-rt} \\
\dot{d}(t) &= d_0 e^{-rt}
\end{align*}
\]  

(3) (4)

- **Exponential distribution with parameter \( \beta \):** \( h_F(x) = \beta \) (memoryless). The fluid limit is the solution to the o.d.e.,

\[
\begin{align*}
\dot{b} &= d \\
\dot{d} &= \beta \Gamma d(1 - b - d) - d
\end{align*}
\]

This is equivalent to the SIR epidemic model with infection rate \( \beta \Gamma \) and recovery rate of 1.
Probability that a destination node without the content, receives it in the given time slot \( = 1 - e^{-\lambda N \alpha (X(k) + Y(k))} \) and similarly for a relay.
Probability that a destination node without the content, receives it in the given time slot

\[ P_x(k) \overset{\text{dist.}}{=} \text{Bin} \left(A(k) - X(k), \lambda_N \alpha (X(k) + Y(k)) \right) \]

\[ P_y(k) \overset{\text{dist.}}{=} \text{Bin} \left(N - A(k) - Y(k), \lambda_N \sigma (X(k) + Y(k)) \right) \]

\[ Q_{xy}(k) \overset{\text{dist.}}{=} \text{Bin} \left(Y(k), \frac{\gamma_N D(k)}{1 - \gamma_N B(k)} \right) \]
Drift Equations

\[
X(k + 1) - X(k) = \lambda_N \alpha (X(k) + Y(k))(A(k) - X(k)) \\
+ \frac{\gamma_N D(k)}{1 - \gamma_N B(k)} Y(k) + Z_x(k)
\]

\[
Y(k + 1) - Y(k) = \lambda_N \sigma (X(k) + Y(k))(N - A(k) - Y(k)) \\
- \frac{\gamma_N D(k)}{1 - \gamma_N B(k)} Y(k) + Z_y(k)
\]

where \(Z_x(k)\) and \(Z_y(k)\) are noise terms with zero mean conditional on the history of the joint evolution process until period \(k\).

Obtain fluid limit by working with the fractional scaled process which evolves over mini-slots of width \(\frac{1}{N}\).
Theorem

Given the joint evolution Markov process \((\tilde{B}^N(t), \tilde{D}^N(t), \tilde{X}^N(t), \tilde{Y}^N(t))\), we have for each \(T > 0\) and each \(\epsilon > 0\),

\[
\mathbb{P}\left( \sup_{0 \leq u \leq T} \left\| (\tilde{B}^N(\lfloor Nu \rfloor), \tilde{D}^N(\lfloor Nu \rfloor), \tilde{X}^N(\lfloor Nu \rfloor), \tilde{Y}^N(\lfloor Nu \rfloor)) - (b(u), d(u), x(u), y(u)) \right\| > \epsilon \right) \xrightarrow{N \to \infty} 0
\]

where \((b(u), d(u), x(u), y(u))\) is the unique solution to

\[
\begin{align*}
\dot{b} &= d; \\
\dot{d} &= \frac{\Gamma d}{1 - \Gamma b} (1 - b - d) - d \quad (5) \\
\dot{x} &= \lambda \alpha (x + y)(a - x) + \frac{\Gamma d}{1 - \Gamma b} y \\
\dot{y} &= \lambda \sigma (x + y)(1 - a - y) - \frac{\Gamma d}{1 - \Gamma b} y \quad (7)
\end{align*}
\]

with initial conditions \((b(0) = 0, d(0) = d_0, x(0) = x_0, y(0) = y_0)\).
Figure: Comparison of the scaled HILT-SI process for various values of $N$ with the corresponding fluid limit.
Figure: Comparison of the unscaled HILT-SI process ($N = 1000$) with the corresponding fluid limit. The solid lines indicate the evolution of o.d.e. solutions.
Outline

1. Motivation
2. System Model
3. Fluid limits
4. Optimization Problems
5. Concluding Remarks
Interest evolution

Content creators: Wish to maximize the level of popularity achieved.

Do not have control over influence weight $\Gamma$ or the threshold distribution $F$.

Only parameter under control is $d_0$.

Optimal $d_0$ to obtain given $b_\infty$:

$$d_0 = b_\infty \left(1 - \frac{1}{1 - \Gamma}\right)$$

(8)

Time to reach target $\beta$ ($\beta < d_0$), given $d_0$:

$$T(\beta, d_0, \Gamma) = \frac{1}{r_0 \ln \left(\frac{1}{1 - \beta d_0 r_0}\right)}$$

(9)

with $r_0 = 1 - \Gamma + \Gamma d_0$. 

V. Srinivasan (IISc, Bangalore)
Interest evolution

- Content creators: Wish to maximize the level of popularity achieved
- Do not have control over influence weight $\Gamma$ or the threshold distribution $F$,
- Only parameter under control is $d_0$
Interest evolution

- Content creators: Wish to maximize the level of popularity achieved
- Do not have control over influence weight $\Gamma$ or the threshold distribution $F$,
- Only parameter under control is $d_0$

**Optimal $d_0$ to obtain given $b_\infty$**

$$d_0 = \frac{b_\infty (1 - \Gamma)}{1 - b_\infty \Gamma} \quad (8)$$

Time to reach target $\beta$ ($\beta < d_0$), given $d_0$

$$T(\beta, d_0, \Gamma) = \frac{1}{r} \ln \left( \frac{1 - r}{1 - \beta d_0 r} \right) \quad (9)$$

with $r = 1 - \Gamma + \Gamma d_0$. 

V. Srinivasan (IISc, Bangalore)
Interest evolution

- Content creators: Wish to maximize the level of popularity achieved
- Do not have control over influence weight $\Gamma$ or the threshold distribution $F$,
- Only parameter under control is $d_0$

**Optimal $d_0$ to obtain given $b_\infty$**

$$d_0 = \frac{b_\infty (1 - \Gamma)}{1 - b_\infty \Gamma}$$  \hspace{1cm} (8)

**Time to reach target $\beta$ ($\beta < \frac{d_0}{r}$), given $d_0$**

$$T(\beta, d_0, \Gamma) = \frac{1}{r} \ln \left( \frac{1 - r}{1 - \frac{\beta}{d_0} r} \right)$$  \hspace{1cm} (9)

with $r = 1 - \Gamma + \Gamma d_0$. 
Optimizations in Coevolution

- Delivering to as many destinations by a fixed time
- Content is time-dependent and its usefulness expires by that fixed time
- Maximize target spread
  \[ \max \{ \sigma : y(\tau) \leq \zeta \} \]
- Deliver the content to a given fraction of destinations as early as possible
  \[ \tau_{\eta} = \inf \{ t : x(t) \geq \eta \} \]
- Minimize reach time
  \[ \min \{ \sigma : y(\tau_{\eta}) \leq \zeta \} \]

In both cases, the constraint is on the number of wasted copies to relays.
Optimizations in Coevolution

- Delivering to as many destinations as possible by a fixed time
- Content is time-dependent and its usefulness expires by that fixed time

Maximize target spread

\[
\max \{ \sigma : y(\tau) \leq \zeta \} = \max
\]

Deliver the content to a given fraction of destinations as early as possible

Define

\[
\tau_{\eta} = \inf \{ t : x(t) \geq \eta \} \]

Minimize reach time

\[
\min \{ \sigma : y(\tau_{\eta}) \leq \zeta \} = \min
\]

In both cases, the constraint is on the number of wasted copies to relays.
Optimizations in Coevolution

- Delivering to as many destinations as possible by a fixed time
- Content is time-dependent and its usefulness expires by that fixed time

Maximize target spread

$$\max_{\{\sigma: y(\tau) \leq \zeta\}} x(\tau)$$
Optimizations in Coevolution

- Delivering to as many destinations as possible by a fixed time
- Content is time-dependent and its usefulness expires by that fixed time

Maximize target spread

\[ \max_{\{\sigma : y(\tau) \leq \zeta\}} x(\tau) \]

- Deliver the content to a given fraction of destinations as early as possible
Optimizations in Coevolution

- Delivering to as many destinations as possible by a fixed time
- Content is time-dependent and its usefulness expires by that fixed time

Maximize target spread

\[ \max \{ \sigma : y(\tau) \leq \zeta \} \]

- Deliver the content to a given fraction of destinations as early as possible
- Define \( \tau_\eta = \inf \{ t : x(t) \geq \eta \} \)

Minimize reach time

\[ \min \{ \sigma : y(\tau_\eta) \leq \zeta \} \]

- In both cases, the constraint is on the number of wasted copies to relays
Maximize target spread (Variation w.r.t. $\tau$)

- $\tau$ - Target time
- $\zeta$ - Constraint on wasted copies
- $\sigma$ - Copy probability to relays

Figure: Maximize target spread: The optimal solution plotted for a fixed value of $\zeta$ and varying $\tau$. 
Maximize target spread (Variation w.r.t. $\zeta$)

- $\tau$ - Target time
- $\zeta$ - Constraint on wasted copies
- $\sigma$ - Copy probability to relays

Figure: Maximize target spread: The optimal solution plotted for a fixed value of $\tau$ and varying $\zeta$. 

V. Srinivasan (IISc, Bangalore) Co-evolution of Popularity and Delivery March 2012 28 / 35
Minimize reach time (Variation w.r.t. $\eta$)

- $\eta$ - Target fraction
- $\tau_\eta$ - Time to reach target fraction
- $\zeta$ - Constraint on wasted copies
- $\sigma$ - Copy probability to relays

Figure: Minimize reach time: The optimal solution plotted for a fixed value of $\zeta$ and varying $\eta$. 
Minimize reach time (Variation w.r.t. $\zeta$)

- $\eta$ - Target fraction
- $\tau_\eta$ - Time to reach target fraction
- $\zeta$ - Constraint on wasted copies
- $\sigma$ - Copy probability to relays

Figure: Minimize reach time: The optimal solution plotted for a fixed value of $\eta$ and varying $\zeta$. 
Outline

1. Motivation
2. System Model
3. Fluid limits
4. Optimization Problems
5. Concluding Remarks
Our Contributions

- Set up Markov models for the co-evolution of content popularity and delivery
- Derive o.d.e. limits (*fluid limits*) from the Markov models
- Show that the popularity evolution model under study, is equivalent to the SIR epidemic model
- Use the fluid limits to solve various optimization problems for both the content creator and the content distributor
Future Work

- Decentralized spread of both popularity and the content
Future Work

- Decentralized spread of both popularity and the content
- Incentive schemes for the relay nodes to carry the content
- *Leecher* behavior - nodes can delete the content after consumption
Future Work

- Decentralized spread of both popularity and the content
- Incentive schemes for the relay nodes to carry the content
- *Leecher* behavior - nodes can delete the content after consumption
- Inter-mobile contact duration not sufficient for full transfer
Future Work

- Decentralized spread of both popularity and the content
- Incentive schemes for the relay nodes to carry the content
- *Leecher* behavior - nodes can delete the content after consumption
- Inter-mobile contact duration not sufficient for full transfer
- Generalize the framework for multiple P2P content
Future Work

- Decentralized spread of both popularity and the content
- Incentive schemes for the relay nodes to carry the content
- *Leecher* behavior - nodes can delete the content after consumption
- Inter-mobile contact duration not sufficient for full transfer
- Generalize the framework for multiple P2P content
Funding Organizations

- Indo-French Center for the Promotion of Advanced Research (CEFIPRA)
- Department of Science and Technology, Govt. of India
Thank you