Proactive-Caching based ICN Architecture for supporting Green Communication in Intelligent Transport System

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Introduction

- Problem statement and research motivation:

  In this research, we state the railway/train system for the case of Intelligent Transport System (ITS).

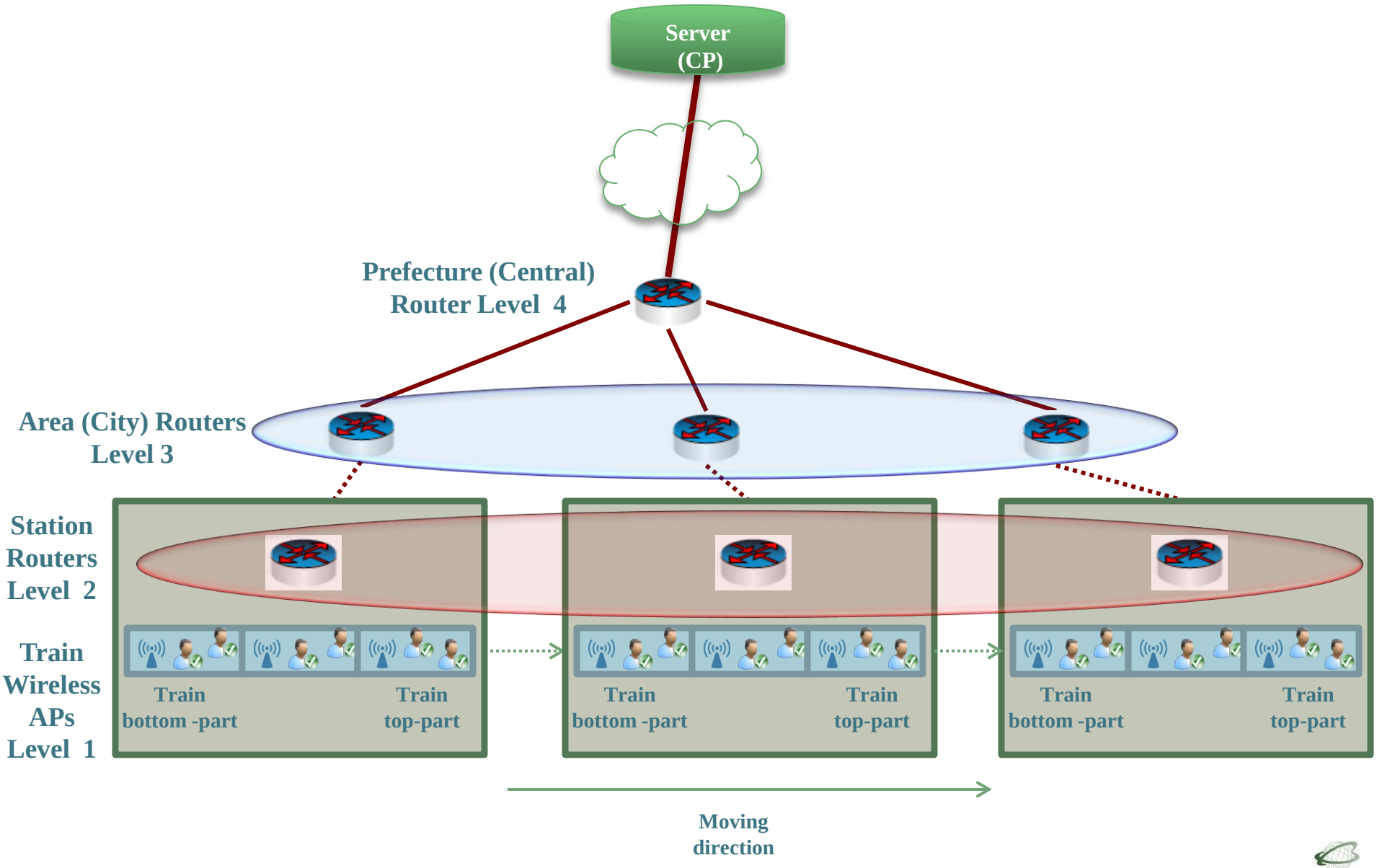
  - Nowadays, train is considered as a popular public transportation vehicle
  - The train's commuters also have high tendency to use their mobile devices for getting their interested information from Internet during the time they spend on train.
  - Better still, the motion of a commuter can be predicted from the path of a train line and the moving direction, stopping time at a specific station along with the moving time between 2 different stations can be pre-determined.

- Proposal goal
  - We aim to construct a concrete model as a prototype of energy-efficient and reliable ICN based wireless communication technology within the context of ITS.

Proposal introduction

- Greening future wireless communication in case of transportation system without degrading network performance by integrating proactive-caching based scheme and green networking into ICN
  - This research proposes a proactive-caching technique in ICN providing the robust and effective content delivery to the mobile nodes (commuters) for transportation system
    - The proactive-caching based scheme fits in the ICN mobility scenarios of transportation system, thanks to our system's "smart scheduler".
  - Moreover, we propose a wireless ICN architecture which can adapt the power consumption of network nodes to the actual values of their optimized utilizations for greening the transportation communication network.
    - This cross-layer power adaption in ICN is based on the popularity of the content and is conducted through adjusting link rate to reduce wasteful energy consumption and provide effective content delivery to the content users.

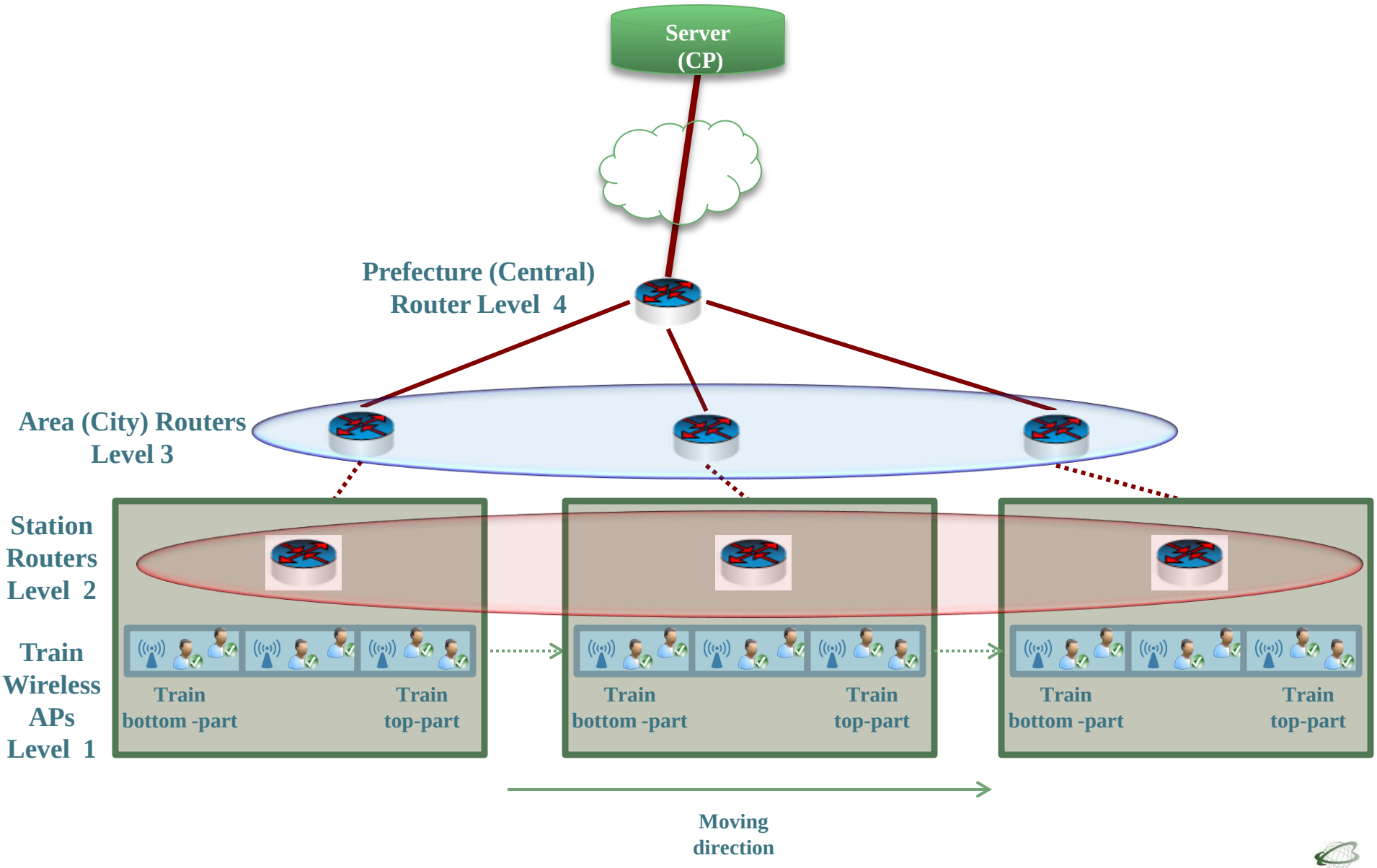
Proposal Green ICN Topology for Train System



Proposed Network Topology for ITS

- Network topology:
  - The network topology include a server/content provider (CP) and Wireless Access Points(APs) at the lowest level with distinguished Content Routers (CRs) at the higher level connected to CP as follows: 1 Wireless AP is equipped at each part (wagon) of a train as first level Content Node (CN). Mobile users can connect to correspondent wireless AP of his current wagon. Wireless AP is connected to content routers (CRs) at stations. CR at station is connected to higher level CRs including: Area (city) CRs act as level 3 router and prefecture (central) CR acts as level 4 router.
  - Assume the ICN system consists of different content and every content is stored at the CP. Wireless APs act as CRs and assume each CR can cache the same maximum number of contents (all content have same size).

Proposal Green ICN Topology for Train System



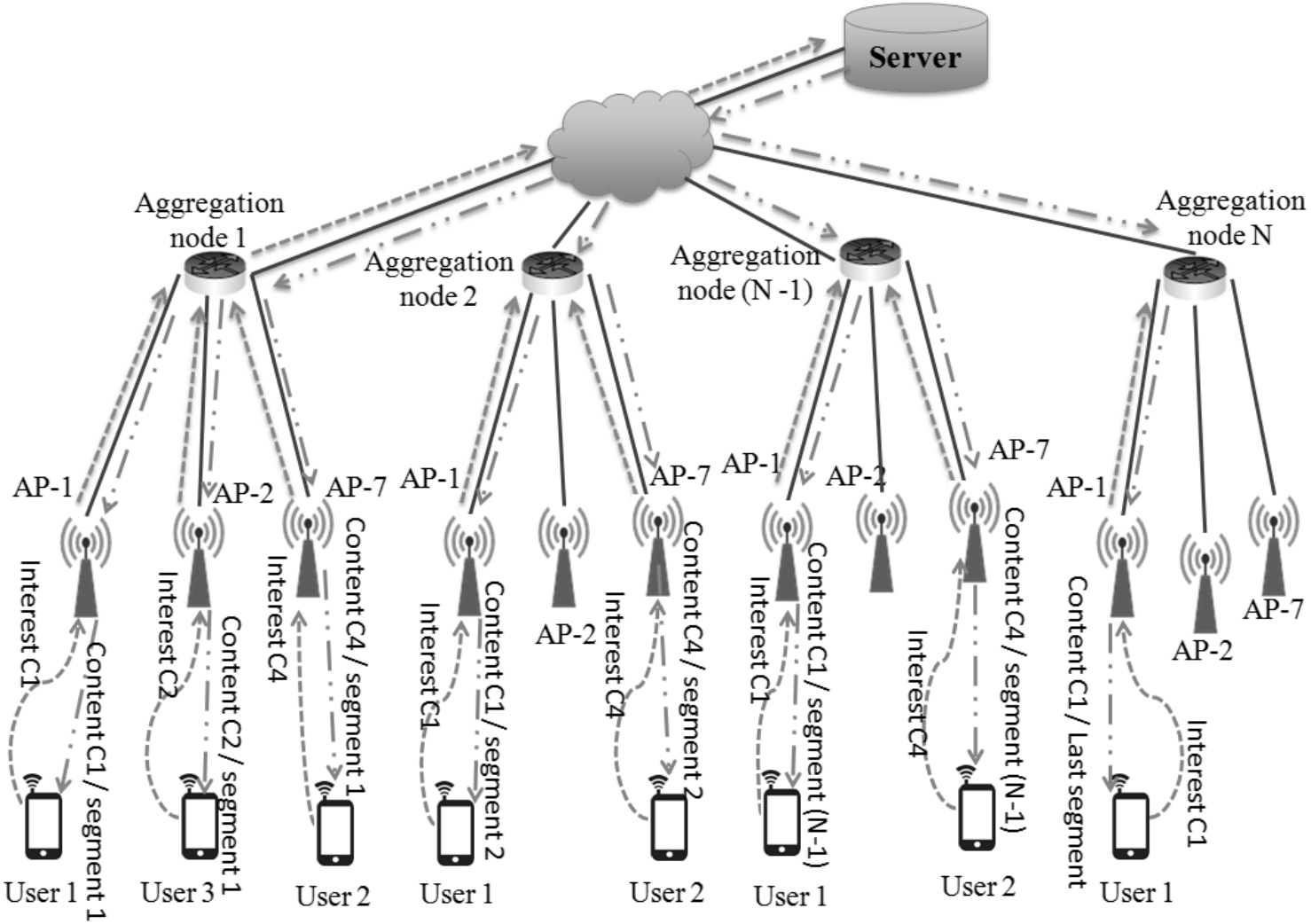
Proactive Caching Scheme

- Proactive Caching Scheme:
  - Choose aggregation points as the location of proactive caching: CRs which are 1 level up of Wireless APs act as aggregation node (Station CRs at level 2), rather than the last node (AP in this case) for enhancing the scope of sharing of the content → populate the same content on the en-route of the interest path and the disjoin-neighbor path.
  - Mechanism: When the content server receives an interest asked for a content, that content data is divided into several segments then is pre-cached to a number of Aggregation nodes
    - Let N is the expected number of stations that one commuter stays on the train, then our proposed system pre-caches content's segments to total of (N-1) stations' CRs away from the first station where the content request is sent to content provider (CP), according to the moving direction of the train line.
    - With this mechanism, a commuter is expected to get his/her full content within a total of N stations and the value of N is used to identify the size of different segments of content will be pre-caches to different stations' CRs. Content delivery is managed by "smart scheduler".

Proactive Caching Scheme

- Proactive Caching Scheme:
  - "Smart scheduler" decides the appropriate location (station) for pre-caching by applying our proposed proactive caching strategy and can calculate the amount of content segment should be cached. Moreover, in order to prevent the redundant content traffic, the pre-caching process for a suitable segment of content c to station N's CR only happens in case station (N-1) still get the interest for content c at that time → deals with the situation that a commuter leaves the train earlier than expected.
  - In order to do this, the system generates fake interest (for same content) from the neighbor Aggregation node. As a result, both of aggregation point (en-route and out of route) fetch the content and cache the content.
  - Therefore, in this system, mobile content user only sends the interest for a specific content to the content server at first Wireless AP → Consequently, the CP working time in our proposal can be substantially reduced compare to existing network systems.

Proactive Caching Scheme



- The flow of interest and the content delivery path with Proactive caching in aggregation node (Station Content Router node)

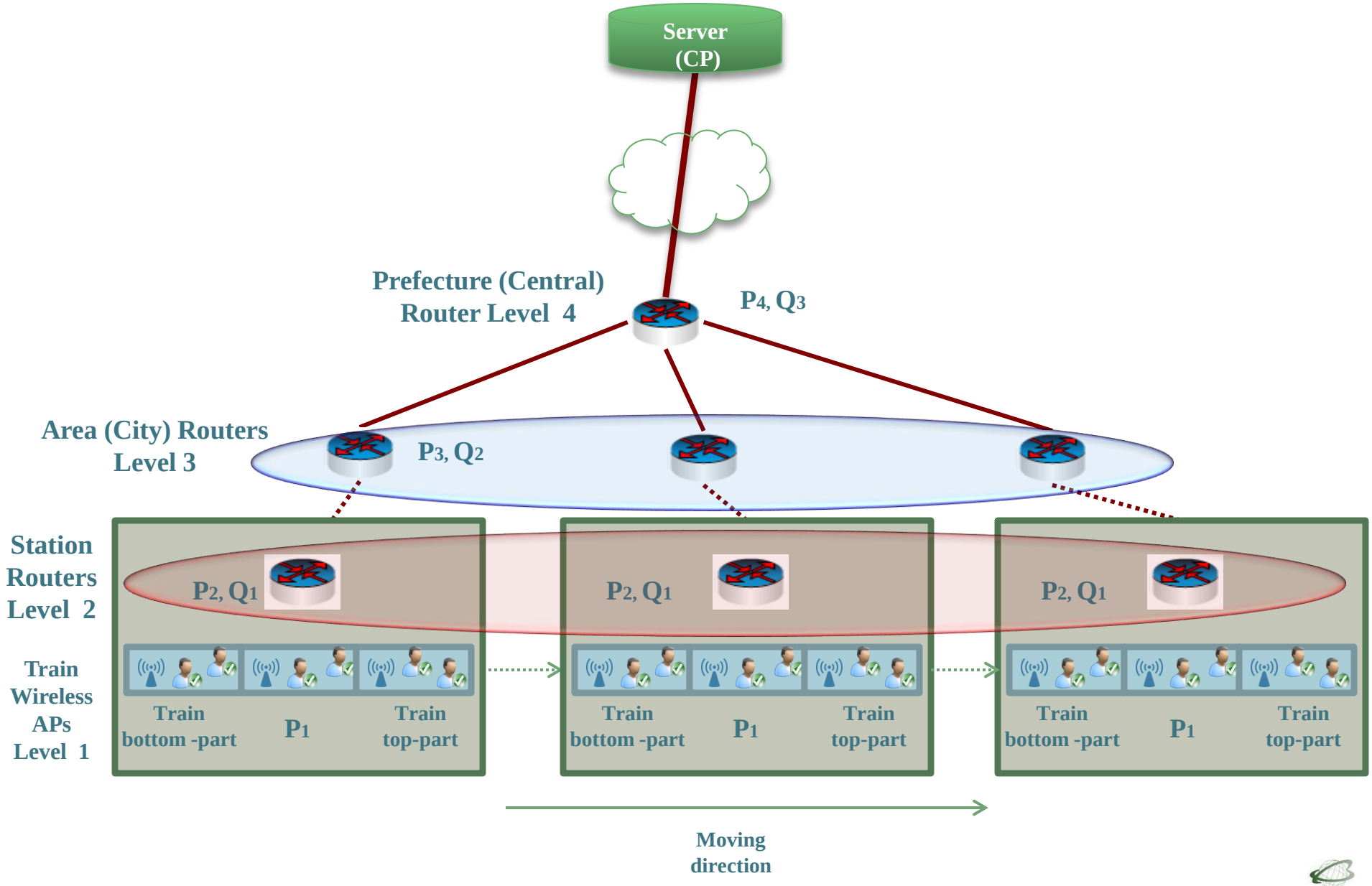
The dynamic Green ICN Architecture

- Network topology
  - Balanced tree based with Server/ Content Provider act as root node (L+1 Level). All routers are allocated into L levels of the tree
  - All the routers (nodes) on the same level have the same probability of containing a content: P_k for the node at level k (Assume network is symmetric and the requests generated by all users are homogeneous)
    - For ICN, a interest only come to the respective server if no router contain its content while in IP network, it is the only way (i.e $P_k = 0$ for i=1,2, … L and $P_k = 1$ for L +1)
    - In case of ICN, the more popular a content is, the higher probability that it can be found in firsts levels of the network topology → 2 kinds of content is defined by following constraints:
      - Popular content: $P_k \geq T_p$
      - Un-popular content: $P_k < T_p$

      where T_p is the threshold value of p_1 for all Content $c \in C$
    - Let Q_k as the probability for a user traversing k levels of the tree to find an interested content $c \in C$, $(K \geq 1)$, then:

$$Q_k = P_{k+1} * \prod_{l=1}^{k} (1 - P_l)$$

Proposal Green ICN Topology for Train System



Content Router Rate Adaptive Scheme

- Let R_k is the link rate enter on level k Content Router for a content $c \in C$ and R_{ICN} is the link rate with caching in the conventional ICN network, then maximum load in first level

$$R_1 > R_k \ (\forall\, k > 1)$$

- Assume that we are using the router which possess the Adaptive Link Rate (ALR) function, which make the content node power consumption proportional to its actual link data rate

- Considering the case when a single or multiple interests come to a Content Node level 1 (AP) but only ask for a single content $c \in C$, then the new enhanced value for R_1
  - For popular content:

$$\text{Enhanced } R_1 = R_{ICN}$$

  - For unpopular content:

$$New\ R_{1,ICN} = (1-\beta)R_{ICN} + \beta\,(R_{ICN}\ \frac{P_1}{T_P})$$

where β is ratio of ICN router which can not provide the ALR function. ($0 \le \beta \le 1$) → $R_1 = R_{ICN}$ in case of popular content and less than R_{ICN} otherwise.

Content Router Rate Adaptive Scheme

- Let S_k is the set of content come to a level k router and S is maximum number of contents (assume that all content have same size) that each ICN routers can cache → Enhanced R_1
  - In case there is at least one popular content is cached at first level:

    → Enhanced $R_1 = R_{ICN}$
  - Otherwise (only unpopular content(s) in the cache of AP)

$$Enhanced\ R_{1,ICN} = (1-\beta)R_{ICN} + \beta\,(R_{ICN}\ \frac{\max P_{1c}}{T_P})\ \ (*)$$

- Then the link rate of ICN router at higher level will adapt to the popular of the content c and Enhanced R_1. For a given level k, then the enhanced link rate of ICN content node become (k-ICN node, with $1 < k \leq 4$)
  - For popular content(s):

$$Enhanced\ R_{k,ICN} = (1-\beta)R_{ICN} + \beta\,\{R_{ICN}\ [1-\min(P_{1c} + \sum_{l=1}^{k-2} Q_{lc})]\}$$

  - Otherwise

$$Enhanced\ R_{k,ICN} = Enhanced\ R_1\ [1-\min(P_{1c} + \sum_{l=1}^{k-2} Q_{lc})]\}$$

Content Router Rate Adaptive Scheme

- Then we define the Enhanced Link Adjusting Factor E_A as

$$E_A = \frac{Enhanced\ R_{k,ICN}}{R_{ICN}}\ (0 < E_A \leq 1)$$

- → Since we assume that all the CNs are equipped with ALR function, the enhanced value of operating energy consumption of Content Node at level k in ICN ($E_{R2-ICN,k}$) can be identified as

$$\text{Enhanced } E_{R2-ICN,k} = E_A \times E_{R2-ICN}$$

NOTE: In case of unpopular content from (*), if Enhanced $E_{R2-ICN,k} < E_{R2-AP,base}$, then let (take) Enhanced $E_{R2-ICN,k} = E_{R2-AP,base}$

- Where $E_{R2-AP,base}$ is the base-energy (the minimum amount of energy that an AP need to maintain)

- → For this proposed ICN model, when a content gets more popular then the expected number of hops (levels) that user have to travel would decrease then make the load of the network decrease and diminish the transport energy notably.

Power consumption evaluation of different network systems

$$E_{IP} = N\ E_{R-IP} + E_S$$
$$= N\,P_{R1-IP}\ T_w + N_1\ P_{R2-IP}\ T_w + N_2\ P_{R2,AP-IP}\ T_w + (P_{S1}\ T_w + P_{S2}\ T_w + P_{S3}\,T_w)$$

where $E_{R\text{-}IP}$, E_S are the energy consumed by a IP router and energy consumed by the server; $P_{R1\text{-}IP}$, $P_{R2\text{-}IP}$, $P_{R2,AP\text{-}IP}$ are the embodied power of a network node (router/AP), working power of a IP router, and working power of an AP, respectively; N_1, N_2 and N are the number of routers, number of APs, and number of CNs respectively ($N_1 + N_2 = N$) and P_{S1}, P_{S2}, P_{S3} are the embodied power, power for server storage and operating power of a server (same value for both ICN and IP based network system), respectively. Besides, T_W is the working time of the whole network system.

$$E_{ICN} = N\,E_{R-ICN} + E_S = N\,(P_{R1-ICN}\ T_w + P_{R3-ICN}\ T_w) + N_1\ P_{R2-ICN}\ T_w + N_2\ P_{R2-ICN,AP}\ T_w + (P_{S1}\ T_w + P_{S2}\ T_w + P_{S3}\,T_w)$$

where $P_{R1\text{-}ICN}$, $P_{R2\text{-}ICN}$, $P_{R3\text{-}ICN}$ are the embodied power, working power and power to cache memory of a ICN CN (CR/AP), respectively. For the purpose of power consumption evaluation, both the current IP-based network system and conventional ICN system share the same power consumption for servers, whereas a ICN node consumes slightly higher power compared to a normal IP node because of the CN's caching function.

$$Proposal\ E_{ICN} = \sum_{k=1}^{N} Enhanced\ \ E_{R-ICN,r_k} + Enhanced\ \ E_{S-ICN}$$
$$\sum_{k=1}^{N} Enhanced\ \ E_{R-ICN,r_k} = N\,(P_{R1-ICN}\ T_w + P_{R3-ICN}\ T_w) + \sum_{k=1}^{N} Enhanced\ P_{R2-ICN,r_k}\ T_{Or_k}$$
$$Enhanced\ E_{S-ICN} = (P_{S1}\ T_w + P_{S2}\ T_w) + [P_F\,T_{O_s} + P_I\,(T_w - T_{O_s})]$$

where T_{Or_k} is the operating time of CN r_k with proposed ALR design, and T_{O_s} is the operating time of server S. Besides, assume that systems user server (CP) with 2 specific state: Idle mode when no content interest send to server and Full mode otherwise (there is at least one interest come to CP). Then let P_F *and* P_I are working power of Full mode and Idle mode, respectively.

Proposal Evaluation

- Simulation parameters (in ndnSIM)

Simulation Parameters	
Connection bandwidth	1Gbps
Content size	1000MB
Payload size (Content Chunk size)	1024 bytes
Content Store Size	20,000 objects
Number of Station CRS (Aggregation Node)	4
Numbers of child nodes which each “parent” has	2
Content request rate	25% of network utilization
Content Popularity distribution	Zipf Distribution (similar to Zip-like distribution)
L. Breslau, P. Cao, L. Fan, G. Phillips, and S. Shenker. Web Caching and Zipf-like Distributions: Evidence and Implications. In Proc. Of INFOCOM, 1999	
Time stay at each Station &Time move between 2 stations	18s & 90s

Proposal Evaluation and Result

- Simulation results

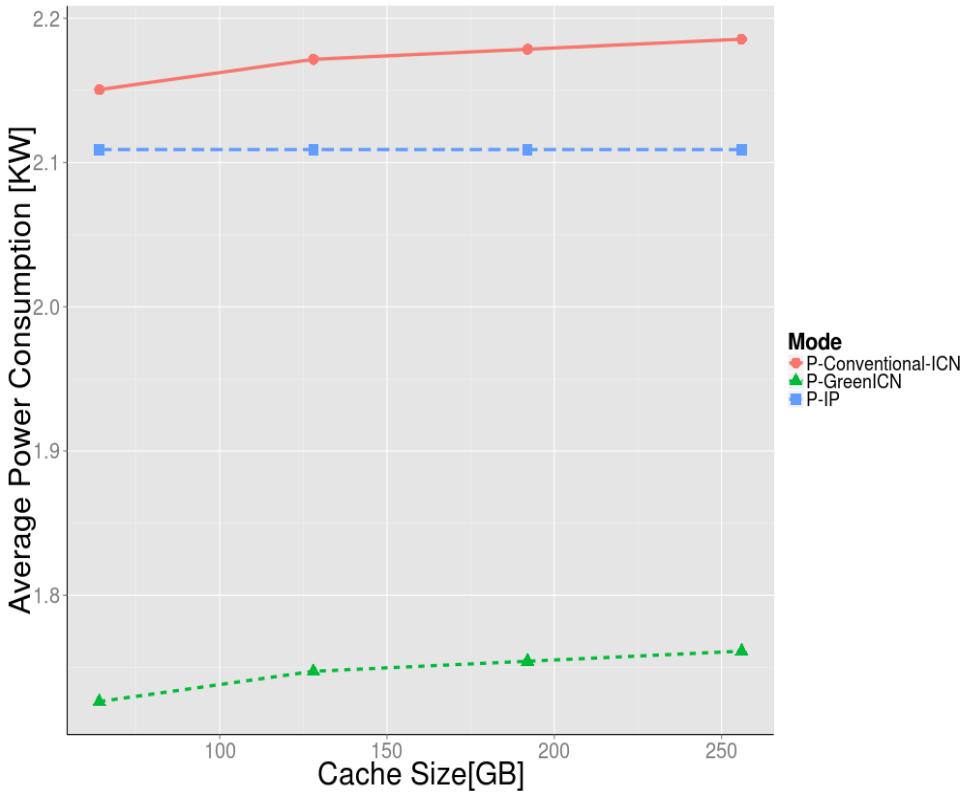


Figure: Power consumption comparison in case of different cache size (GB)

- Though the conventional ICN system consumes slightly more power than the current IP-based system, simulation with the tree topology proves the efficiency of our proposal Green ICN system compared to the IP-based system in term of power consumption, especially in case of low traffic period.

- This is because, when proposal ICN system approaches the stable state then many contents already cached in some router then, as a result, at that time other routers may cache the desired contents and servers may get into idle state.

Proposal Evaluation and Result

- Simulation results

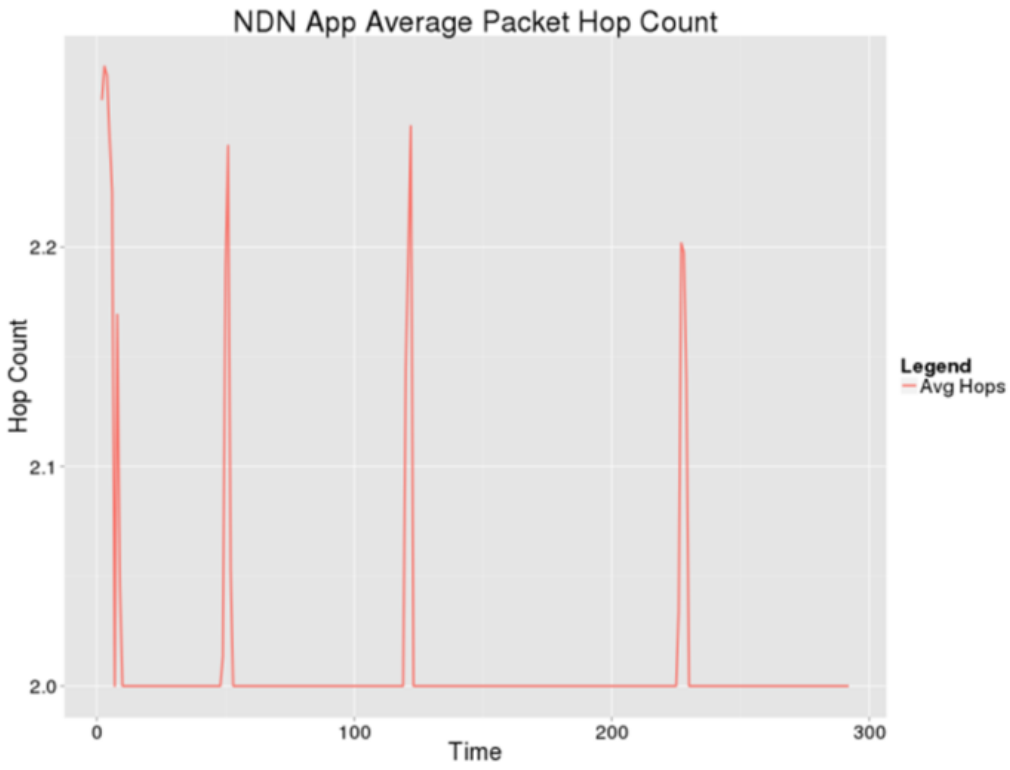


Figure: Performance evaluation for Average Hop Count

Average Packet Hop count: the Average Packet Hop count is kept stable at value of 2 with the simulation time as shown in the Fig. 3, except the cases that the Mobile Node (MN) is involved in the Hand-offs period when it move to change the Point of Attachment (PoA). This is the result of our proactive caching strategy.

Conclusion and future work

- In this paper, we propose and evaluate a dynamic model utilizing pre-fetching technique for wireless content access in case of ITS (train/railway system)
  - We exploit both ICN mobility and innovated proactive caching scheme together to raise energy efficiency and effectiveness for the goal of green mobility in ICN.
  - The simulation results in ndnSIM corroborate our theoretical idea and prove the efficiency of our proposed scheme, compared to both current IP-based network and conventional ICN

- For future work
  - We intend to extend our proactive caching scheme in ICN more practical use-cases with different kinds of content services, such as: VoIP, Multimedia Services, etc in larger scalability and complete topology for Future Mobile Communication.
  - We also plan to extend our study for the case of Wireless/ Mobile Network together with proactive caching-based mechanism for our future work.

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[7] http://www.greenicn.org/

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Thank you very much for your attention!

ありがとうございました

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