On the Incentives and Incremental Deployments of ICN Technologies for OTT Services

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With the explosion of broadband Over-The-Top (OTT) services, the Internet is autonomously migrating toward overlay and incrementally deployable content distribution infrastructures. Information-Centric Networking (ICN) technologies are the natural candidates to efficiently distribute popular content to users. However, the strategic incentives in exploiting ICN, for both users and ISPs, are much less understood to date. In this article we highlight strategic incentives for ICN overlay adoption in OTT services, that is, we discus how OTTs shall shape their prices to motivate ICN overlay usages.

The ubiquity of broadband Internet is at the origin of the emergence of Over-The-Top (OTT) subscription services such as Netflix or Hulu. The specificity of OTTs is to provide broadband video and audio delivery to Internet users without a particular dedicated involvement of their Internet Service Provider (ISP). To offer high quality multimedia content distribution, OTTs commonly rely on distribution infrastructures with multiple points of presence connected at main Internet exchange points. This need for advanced distribution infrastructures derives from the current technical limitations of TCP/IP that bind communications to the location of the server by using IP addresses. Moreover, the multimedia nature of OTT services requires low latency, jitter, and loss rate. Hence, OTT servers should not be in topologically and performance constrained locations, as it usually happens in P2P networks, and should limit the number of relay hops as much as possible. OTTs could simplify their distribution infrastructure by following an Information-Centric Networking (ICN) [1] approach. ICN relies on the “routing by name” paradigm and leverages in-network caching where intermediate network nodes can cache any piece of data passing through them. This caching capability of ICN networks ensures that popular content is cached on routers close to the clients [2].

As a matter of fact, ICN can significantly increase content distribution efficiency with respect to legacy technology [1,2]. When capital expenditures are not insurmountable obstacles to deploy ICN-capable network elements, the advantage for ISPs to deploy ICN inside their networks is immediate as ICN inherently helps in reducing overall link usage. The advantage is less straightforward for OTTs as they are very sensitive to network conditions of networks they do not control. A reasonable way for OTTs to profit from ICN is to construct an ICN overlay that interconnects OTT servers and clients. The rational behind using overlays is that they can be incrementally deployed in the Internet and hence do not require network nodes from the underlay (i.e. ISP’s equipment) to explicitly participate in the ICN network. In the ICN overlay, every node implements the same ICN protocol, and OTT clients caching contents can deliver them to other clients on behalf of the OTT provider. The routing system determines from which node customers retrieve the content (either a caching node or directly from a server).

Figure 1 synthetizes the simplest interaction between the stakeholders (OTT, caching customer nodes, non-caching customer nodes) for the baseline case of three ICN nodes beyond which two are hosted by OTT consumers (nodes II and I in the figure) and one is hosted by an OTT provider server (node OTT in the figure). The routing system allows a customer node to retrieve the content either directly from the OTT server node or from the other customer node. In the figure, arrows indicate the direction of requests to obtain content and the label specifies the strategy adopted by the node performing the request. Customer I (resp. II) has the choice between four strategies: it can retrieve the content from the OTT server, caching it for customer II (resp. I) (label = OTT^c); it can retrieve it from the OTT server, not caching it (label = OTT); it can retrieve it from the other customer, caching it (label = II^c (resp. I^c)); or it can retrieve it from the other customer, not caching it (label = II (resp. I)). For the sake of simplification we do not show impossible strategy combinations.

In our study, we adopt the standpoint of the OTT provider willing to incent the usage of the ICN overlay among its customers, under the assumption that using the ICN overlay is always profitable for the OTT provider: when customers retrieve content from the OTT server it is equivalent to not using the overlay; and the OTT infrastructure load is reduced when customers retrieve content from other customers. In our study, we also assume that customers are independent and selfish, i.e. not prone to binding cooperation in ICN provisioning. In this context we show that with the right incentives the OTT provider can make their customers coor-

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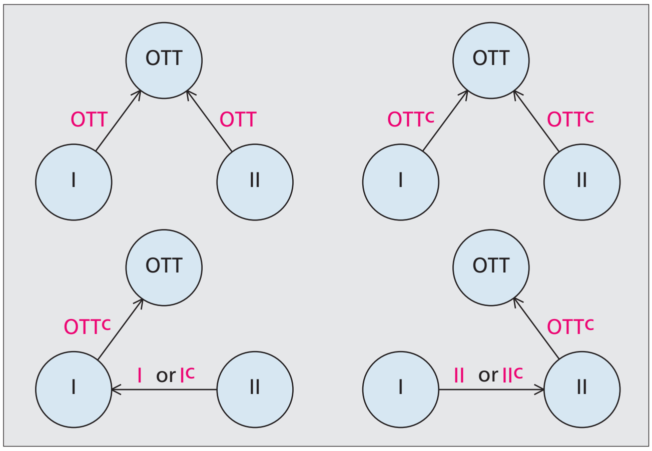

Figure 1. Synthetic representation of ICN overlay strategies for OTT consumers.

dinate to form a caching ICN overlay. Without loss of generality we can translate these incentives into scaling prices and discount even though incentive might not be pecuniary (e.g. access to augmented services). Game theory is the natural tool to study the interaction between selfish and independent actors such as the stakeholders of the OTT-enabled ICN overlay. We provide a comprehensive simple model thanks to which an OTT provider can design its incentive mechanism under the awareness of users' strategies and approximate scales of ICN overlay's operational costs. We show by an intuitive explanation of the resulting ICN overlay game if and when the ICN overlay makes sense, under three different basic business models: the "McDuck" business model, the "Philanthropist" business model, and a specific business model we argue as the wisest for OTT-enabled ICN overlays.

The article is organized as follows. We first give an overview of ICN. We then characterize the ICN overlay game modeling, and detail its application to the three business model cases. Finally, we specify requirements for the possible related policy-based ICN protocol functionalities.

Information-Centric Networking (ICN)

Information-Centric Networking (ICN) proposes to rethink the provisioning paradigm of communication data networks, while removing any notion of location or topology to only keep the notion of content name [1]. In ICN, content can be anywhere in the network, potentially moving or replicated in many locations. As opposed to TCP/IP — where a client must first determine the IP address (i.e. the location) of a server that can provide content, and then initiate a connection to the server host — in ICN a client simply has to know the name of the content it is interested in, and announce its interest in retrieving that content to the network, which will eventually look for it and deliver it back to the client. As communications in ICN depend neither on content consumers' locations nor on content producers' locations, ICN naturally offers support to multipath and mobility. More interestingly, as the exact origin of a piece of data is taken apart content exchanges, any node in the network can provide the content on behalf of the node that produced that content, as long as it disposes of a valid copy of it.

Various ICN solutions have been proposed [1], ranging from clean-slate solutions implying a comprehensive restructuring of the network infrastructure, to incrementally deployable ones, among which is the possibility of building ICN overlay networks. In this article, we ignore technological details and abstract the ICN paradigm as a mechanism to retrieve content independently of its location via an ICN overlay, such that in-network caching is possible in ICN overlay nodes.

Incentives for Client Collaboration Within an ICN Service Delivery Overlay

As detailed in the introduction, we assume that the OTT provider has a competitive gain of adopting ICN as it simplifies its infrastructure and hence reduces its OPEX and CAPEX. However, this requires the collaboration of its consumers, which are not especially prone to cooperation, as they are independent actors. We therefore determine the conditions required for consumers to implicitly coordinate in an ICN overlay in a strategically justified way. While beneficial for the OTT provider, it is not clear under which situations the ICN overlay can be of benefit to OTT consumers, or otherwise stated, how the OTT provider can design its prices and discounts[1] so that the ICN overlay does benefit OTT consumers too.

To qualify the potential adoption of the ICN overlay by the consumers, we take the baseline scenario where no ICN overlay is used as a reference point: the customer adopts ICN if its cost is lower than this reference. From this basis, to give incentives to consumers to retrieve content from other consumers involved in the ICN overlay instead of directly from the OTT provider, the latter applies a *supplement* p when the content is retrieved directly from it. On the other hand, the customer receives a *discount* d (e.g. a coupon or the access to a member zone) if she agrees to redistribute the content on behalf of the provider via the ICN overlay. The values of p and d are decided by the OTT based on various elements such as the popularity of the content or the location of the customer. The computation of the optimal p and d values to maximize profit margins is out of the scope of this article as it mostly depends on OTT provider business structure (e.g. sell at 0.99$ or for free?). Furthermore, OTT customers involved in the redistribution of content face a *caching cost* c of keeping a copy of the content for later distribution (e.g. memory) and a *redistribution cost* r to relay the copy to other consumers (e.g. bandwidth or energy). To avoid multiple hops in the overlay and thus performance penalties, content can be retrieved from another consumer, say II, only if II caches a copy of the content.

All in all, the generic cost structure for consumers can be expressed by $p + c + r - d$. While the producer is the one deciding on the supplement and the discount, r and c represent operational expenditures at the consumer level. It is worth stressing that in this article we concentrate on the atomic ICN overlay game with complete information where pricing components do not change in the lapse of time during which a content access strategy is taken, and we leave a detailed sensibility analysis for further work.

Under the cost modeling presented above and the available strategy set described via Fig. 1, it is possible to qualify the incentive compatibility of the incremental deployment of an ICN overlay for OTT services. For the sake of realism, OTT users and providers should be considered as selfish and independent actors, whose actions can be implemented via a deterministic content access process, which by definition should model rational decisions. Therefore, under rationality

[1] *Remember that we use the notion of price and discount in its abstracted sense, which does not necessarily imply pecuniary implications.*

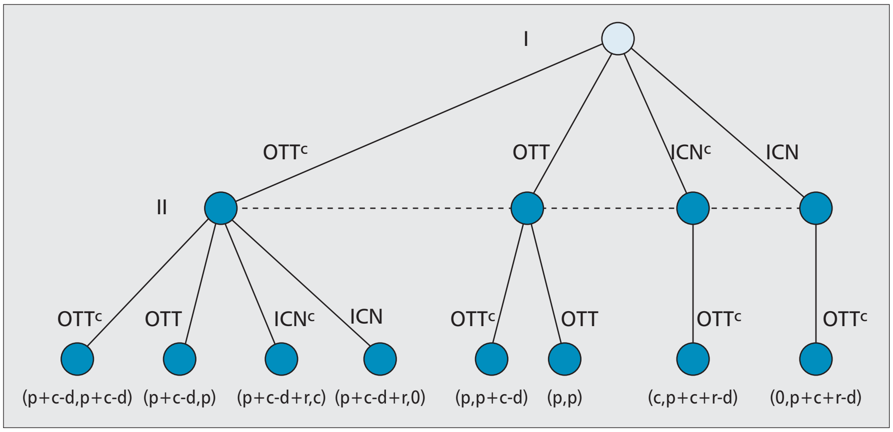

Figure 2. ICN overlay game strategy tree.

assumptions, the strategic interaction between ICN overlay users can be modeled with the non-cooperative game we call "ICN overlay game". Figure 2, which uses the same notation as Figure 1 and which considers two OTT users, shows costs resulting for the different possible strategy profiles for the two OTT customers (customer I, customer II; note that the horizontal line indicates that actions of customers I and II do not need to be consecutive). The cost model assumes that the routing system in the overlay allows retrieving content either directly from an OTT server or indirectly from another consumer. Strategies that prevent the content to be delivered are omitted in Fig. 2.

Table 1 summarizes, in a strategic form, the cost for each player according to the strategy she follows; the first column contains the possible strategies for user I, the first line those for user II, and in each cell the first line and the second line is the resulting cost for user I and II, respectively, according to their strategies. As the table shows, there are eight possible equilibria that depend on the relations between p, c, d, and r; in a non-cooperative cost game, an equilibrium is a strategy profile such that none of the players is motivated by unilaterally deviating from it (i.e. unilaterally changing the strategy) because of the higher individual cost such deviations would imply [4]. As a matter of fact, the OTT targets an equilibrium where a consumer retrieves content from the other consumer (e.g. I gets it from II). These equilibria are marked in green in Table 1; they are (ICN^c, OTT^c), (ICN, OTT^c) , (OTT^c, ICN^c), and (OTT^c, ICN), noting that for both the strategies "ICN" and "ICN^c" the ICN overlay is used to retrieve the content, but for the ICN strategy the content is not cached for external users, nor for internal users (e.g. in the case the OTT consumer is an ISP); the remaining equilibria should be avoided, otherwise the usage of the ICN overlay would not make strategic sense. In the following, we explore the space of possible outcomes and see which equilibrium can be reached under which conditions. More particularly, we distinguish three main cases corresponding to three different and realistic business models that can be enforced by the OTT provider via the ICN overlay.

It is important to highlight that, for the sake of presentation, we display the same value for the supplement, the discount, the caching, and the redistribution costs for the two actors (i.e. p, d, c, and r), while in practice there is absolutely no need to have the same components for the different OTT ICN customers. Caching and redistribution costs, as well as prices and discount values, can differ for different customers with no impact on the following statements, as the strategic considerations in the selection of equilibria are strictly based on the comparison of unilateral cost profiles (i.e. actors do not compare their costs to other players' costs when taking strategy decisions). It is also important to stress that, for the same reason, the generalization of the ICN overlay game to more than two players does not change the following statements. Under the reasonable assumption that the price, caching, and redistribution costs do not depend on which ICN node delivers or retrieves the content, the strategies "ICN" and "ICN^c" would no longer imply the content is retrieved from II or from I, for instance, but that it is retrieved from the closest ICN node in case of shortest path ICN routing or from the best neighbor according to some local policy metrics.

Case 1: The McDuck Case

When it is too expensive for an OTT provider to maintain a geo-distributed infrastructure by itself, it can outsource the distribution infrastructure to a specialized service provider. As a result, OTT customers pay the OTT provider, which partially uses this income to remunerate the service provider for the delivery of content. This situation corresponds to the current content delivery network (CDN) model. However, we go one step further and ask the question whether two such service providers that are paid to deliver the same content on behalf of an OTT provider would collaborate, which strongly deviates from the legacy CDN business model. If by contract the service provider had to keep a copy of the content and distribute it to any consumer asking for it (i.e. it is paid for that), then each service provider becomes a "player" given its interaction with other service providers. In such a case we can account for the retribution paid by the OTT provider simply as a discount (the price is zero) and two options are possible: either the OTT customer obtains the content from the OTT provider and caches it (i.e. OTT^c), or it retrieves it from the collaboration service provider and caches it (i.e. ICN^c). The resulting game form is depicted in Table 2.

Therefore, saying that the OTT provider pays the consumers enough to cover ICN overlay costs and ensure they will cache corresponds to saying that d is larger than all other components combined. Indeed, for such a McDuck business model, we can derive that $d \gg p + c + r$, i.e. the OTT provider has the means to largely cover ICN overlay costs. However, in this case the only equilibrium is (OTT^c, OTT^c) = ($\sim -d$, $\sim -d$). This outcome means that applying large discounts (i.e. remunerating the players), OTT customers have no incentives to participate in any ICN overlay. An ICN overlay between them will not reasonably be used at all. Therefore, if an OTT producer decides to outsource the content delivery to its customers as if they were delivery networks,

I \ II	OTT^c	OTT	ICN^c from I	ICN from I
OTT^c	p + c - d p + c - d	p + c - d p	p + c - d + r c	p + c - d + r 0
OTT	p p + c - d	p p	N/A	N/A
ICN^c from II	c p + c - d + r	N/A	N/A	N/A
ICN from II	0 p + c - d + r	N/A	N/A	N/A

Table 1. Generic ICN overlay game.

I \ II	OTT^c	ICN^c
OTT^c	$\sim -d$ $\sim -d$	$\sim -d$ ~ 0
ICN^c	~ 0 $\sim -d$	N/A

$d >> p;\ p, c, r \sim 0$

Table 2. The McDuck case: the ICN overlay is not used.

there is no unilateral incentive to make cached content available to other OTT consumers. Otherwise stated, this business model does not make strategic sense for ICN overlays.

Case 2: The Philanthropist Case

The first case can be seen as the extreme situation where the offered discount is so high that ICN costs become negligible. In this second case, we take the other extreme where the provider offers no discount at all. This situation corresponds, but is not limited to, a case where the OTT provider is not willing to experience losses, but where its goal is to maximize the global utility of the network instead of its own profit (hence adopting a philanthropic business behavior). In this case, the provider allows customers to freely exchange content between them, but asks for a fee when content is retrieved directly from the provider (i.e. $p > 0$). For instance, this kind of scenario is common for services offering to distribute open-data/unlicensed content where the content by itself can be redistributed freely, but at the cost of receiving advertisements (i.e. the price for the consumer is to follow the advertisements) to cover the distribution infrastructure costs.

As depicted in Table 3, when $d = 0$, five equilibria are possible. (OTT, OTT) corresponds to both actors retrieving the content directly from the provider without caching it, i.e. OTT consumers would not collaborate when following such an equilibrium strategy. The other four equilibria correspond to one actor retrieving the content from the provider and the other actor retrieving it from her. This second actor has the choice of caching or not the content once retrieved, leading to possible equilibria (OTTc, ICN), (OTTc, ICNc) and their respective symmetric. Without any additional knowledge, it is impossible to determine to which equilibrium the OTT customers would converge. However, one can identify two main tendencies:

1 When redistribution and caching costs are not negligible (i.e. $r > 0$, $c > 0$), then the only remaining possible equilibrium is (OTT, OTT), meaning that actors will not adopt the ICN overlay: they will always directly retrieve content from the provider.

2 On the contrary, when redistribution and caching costs can be considered as negligible with respect to supplement (i.e. $r \sim 0$, $c \sim 0$), then we fall back to the five equilibria from the general case of Table 1 (without assumption on r and c). However, in this situation the (OTT, OTT) equilibrium becomes Pareto inferior (i.e. one can pass to another equilibrium decreasing the cost for at least one player without increasing the cost for the other player), and all the other equilibria (i.e. (OTTc, ICN), (OTTc, ICNc) and their respective symmetric) are not Pareto superior to each other and can therefore be considered as equivalent from a strategic perspective. This means that when there is no discount and no cost of participating in the redistributions, rational actors have incentives to get involved in the distribution process and to deploy the ICN overlay.

It is worth noting that in the situation where all components are negligible ($r \sim 0$, $c \sim 0$, $p \sim 0$) and there is no discount, all feasible strategy profiles become equilibria, with the same cost vector (0, 0). This suggests that the OTT provider can enforce the usage of the ICN overlay (e.g. by implementing it directly in the viewer plugin) without causing trouble to actors. At some extent this can be considered as the standard P2P model where incentives to get involved in the overlay come from external factors such as the non-availability of the content elsewhere than via the overlay.

Case 3: The Wise-Man Case

While the first two cases address the ICN overlay game equilibria for extreme discount values, in this third case we consider that the provider offers a moderate discount. A moderate discount is a discount that is of the same order of magnitude as other expenses (i.e. p, c, or r), and is smaller than the amount corresponding to the McDuck business model (Case 1). Such a situation is likely to happen when several OTT providers can offer the same content and there is no customer lock-in to one particular provider. In such a competitive market, price levels are similar among producers, and consumers are flexible in their OTT choice. Therefore, assuming that using the ICN overlay reduces costs for the OTT provider, the provider can leverage such an ICN overlay to slightly reduce the prices and become more attractive without negative impact on its profit.

As depicted in Table 4, in the situation of a moderate discount such that $p + c > d > 0$, there are three types of equilibria.

- The first corresponds to when the overlay is not used (i.e. (OTT, OTT)).
- The second corresponds to when one OTT consumer retrieves the content from the provider and the other from the first actor, but without participating in content redistribution (i.e. (OTT^c, ICN) and (ICN, OTT^c)); these are, however, no longer equilibria whenever caching costs are not negligible (i.e., $c > 0$).
- The third corresponds to when, instead, the actor retrieving the content via the ICN overlay does cache it too (i.e. (OTT^c, ICN^c) and (ICN^c, OTT^c)).

Even though the first type of equilibrium disfavors the ICN overlay, if the provider intelligently fixes the discount to be greater than the caching and redistribution costs (i.e. $d > r + c$), then (OTT, OTT) becomes an inefficient Pareto-inferior equilibrium. Being rational actors, it follows that the OTT con-

I \ II	OTT^c	OTT	ICN^c from I	ICN from I
OTT^c	$p + c$ $p + c$	$p + c$ p	$p + c + r$ c	$p + c + r$ 0
OTT	p $p + c$	p p	N/A	N/A
ICN^c from II	c $p + c + r$	N/A	N/A	N/A
ICN from II	0 $p + c + r$	N/A	N/A	N/A

$d = 0,\ p > 0,\ r \geq 0,\ c \geq 0$

Table 3. The Philanthropist case: consumers should not spontaneously use the ICN overlay.

I \ II	OTT^c	OTT	ICN^c from I	ICN from I
OTT^c	$p + c - d$ $p + c - d$	$p + c - d$ p	$p + c - d + r$ c	$p + c - d + r$ 0
OTT	p $p + c - d$	Pareto inferior iff $d > r + c$ p p	N/A	N/A
ICN^c from II	c $p + c - d + r$	N/A	N/A	N/A
ICN from II	0 $p + c - d + r$	N/A	N/A	N/A

$p > 0, c \geq 0, p + c > d > 0$

Table 4. The Wise-Man case: consumers should spontaneously use the ICN overlay.

sumers will adopt the ICN overlay according to the other types (i.e. with at least one consumer caching the content).

In conclusion, with a discount strictly lower than the price:
- Setting a discount higher than the ICN overlay costs, yet strictly lower than the content price, is therefore the wisest choice to motivate the ICN overlay adoption.
- Under this setting, as far as caching cost are negligible, ICN overlay customers are prone to caching for both their own (internal) and external distribution.
- The amount of discount for the ICN customer should not be too close to the price, although the closer the discount gets to the content price, the more the profile (OTTc, OTTc) becomes appealing as opposed to the ICN overlay equilibria (more precisely, it would become an equilibrium for $d \sim p + c$).

Protocol Design Considerations

This article starts a broad discussion on incentives to migrate to ICN overlay in OTT services, highlighting strategic aspects of such routing-by-name overlay approaches. Even though different solutions exist to construct ICN networks [1], we present four technology independent considerations necessary to witness the adoption of ICN overlays in OTT services. The ultimate OTT goal is to ensure that customers follow the envisioned equilibrium strategy when setting its content's supplements and discounts (i.e. p and d).

ICN forwarding Logic

First, the ICN overlay routing system should be able to distinguish the case when content requests are relayed directly to the OTT provider and when they are retrieved from a caching OTT consumer. How this forwarding logic is managed is a matter of discussion. The OTT provider could either enforce it, for instance in the case it releases the process/plugin needed to access the ICN overlay, or the ICN protocol control-plane could allow the remote management of ICN forwarding.

Incentive Mechanism Design

Second, ICN users should be able to register their strategy to, or their strategy should be trackable by, an entity managed by the OTT provider. This entity should be able to verify whether the forwarding priorities in the nodes involved in the ICN overlay are consistent with the registered strategy. In case of inconsistency between what the OTT provider would expect and what ICN nodes would implement in terms of forwarding priorities, the OTT may:
1) Act on the content supplement and/or on the discount.
2) Restrict content access to the OTT users participating in the ICN overlay.
3) Give the ICN node a suggestion about other ICN nodes from which to retrieve the content via the overlay (in the case many ICN nodes have cached it).

While option 1 would imply complex ad-hoc pricing, and option 2 could be counterproductive for the adoption of the ICN overlay, option 3 appears as a viable solution. Introducing such an OTT-set-ICN-policy metric would still leave the OTT customer the freedom not to choose the ICN overlay in the case the incentives are not compatible (as described in the three business cases above). Depending on the specific deployment of the ICN overlay, ICN nodes may or may not be willing to redistribute much content to many other ICN nodes. The OTT provider would have the means to indirectly control ICN traffic distribution, hence overloading or underloading some nodes depending on its forwarding behavior, besides being willing to meet global content provisioning optimization goals. Such a local policy metric would indeed be very powerful and adequate to allow an OTT to optimize the content delivery chain and mitigate undesirable ICN nodes' behaviors.

Adaptive Collaborative Caching

Third, should the amount of content served by the overlay become important, the OTT provider could take into account the caching nature of ICN storage and adapt its strategy to maximize the traffic served by caches in the network with, for instance, collaborative caching that reduces redundancy to improve cache hit [2, 5].

Consumers Tracking

Finally, most current OTT service providers build their profit from selling advertisements proportionally to their audience (e.g. size of the consumer base, social level, age, etc.). However, as any node can serve content in ICN, requests arriving to the content producer (i.e. the OTT provider) do not reflect the real consumption of its content. Therefore, in order to preserve the business model behind advertisements, ICN solutions used in the frame of OTT will have to provide a way for the providers (or advertisement announcers) to keep track of their consumers, independently of the data-plane.

Conclusions

With the Internet, new digital services can rapidly reach millions of users spread worldwide without having to rely on special involvement of intermediate transit networks. For example, Over-The-Top content providers could leverage their customer resources to allow, on the one hand, improving access performance, and, on the other hand, reducing OTT provider OPEX incurred by directly serving customers. In this context, Information-Centric Networking is an adequate offloading technique, if incrementally deployed as an overlay network. This article analyzes the incentive compatibility in the adoption of an ICN overlay for OTT services and is, as of our knowledge, the first paper to address the topic by following a non-cooperative game theory reasoning. We believe such reasoning is adequate in its non-cooperative nature due to the independency between the involved ICN stakeholders. From our analysis, we assess that:
- The business model currently standing for paying content distribution services does not make strategic sense for ICN overlays as they would not collaborate.
- When there is no discount and no cost of participating in the redistribution of OTT content, OTT customers do have

incentives to get involved in the distribution process via the ICN overlay.
• Setting a discount higher than the ICN overlay's caching and redistribution costs, yet strictly lower than the content price, appears as the wisest choice to motivate the ICN overlay adoption.

These unique specifications for the design of an ICN overlay for OTT content distribution also have relevant implications for ICN protocol design. The OTT provider would need a form of control over the ICN overlay operations. We identify the usage of an OTT-set-policy metric for ICN routing as the most appropriate way to ensure that ICN users follow the equilibrium strategy suggested by our incentive compatibility framework.

In this work we only envisioned the case of ICN overlay over a non-ICN legacy Internet. This model does not preclude the local deployment of ICN networks inside ISPs. However, we leave for future work the understanding of the complex interactions between the underlay and the overlay if the underlay is also composed of collaborating actors and that could thus influence the overlay.

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