Operational Information Content Sum Capacity: Formulation and Examples

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***Abstract*—This paper considers Quality-of-Information (QoI) aware rate allocation policies for multiple access channels. QoI is a recently introduced composite metric which is impacted by a number of attributes including accuracy and timeliness of delivery of information communicated from the source(s) to the destination(s), and as such differs from traditional quality-of-service metrics considered to date. The focus of this work is defining the Operational Information Content Sum Capacity (OICC-S) of a network, as the set of QoI-vectors supported which maximize sum utility of the system. This utility is defined as a function of the QoI attributes provided by the source input, as well as the channel induced attributes that impact the QoI delivered to the destination(s). Optimum rate allocation to maximize the output sum utility and achieve OICC-S of the network is provided, and demonstrated to differ from the solution that provides maximum throughput.**

Keywords: Quality of Information, Rate Allocation, Network Utility Maximization, Scheduling

I. Introduction

Traditional approaches based on Quality of Service (QoS) perform network operations that are agnostic to the application or content of data. This may not lead to best design strategies for tactical networks, where the main goal is sound decision making. To this end, a new paradigm which emphasizes the quality of information by viewing the network as an information source, and developing methods to satisfy quality requirements at the end user is necessary. To characterize information quality, there is growing interest in moving from traditional QoS metrics as throughput, packet delivery ratio, fairness, and delay towards new notions of quality associated with information.

The notion of *Quality-of-Information* (QoI) [1] [2] has been introduced to formally describe this new class of attributes, including provenance [2], accuracy and precision [1] [2], reliability [1], corroboration [2] [3], age/freshness and timeliness [1] [2]. These attributes specify how and by whom information was gathered, under what conditions, how and by whom it was processed. Given the recent interest in defining QoI metrics, it is a natural direction to explore the impact of this new paradigm on fundamental networking operations. Efforts to date in this direction are specific to event detection, see for example [4]. The question of how to make optimal control decisions that optimize performance with respect to these new metrics has been addressed in [5], where scheduling mechanisms are proposed for different mission arrival scenarios on a single link, trading off gain in accuracy with reduction in freshness.

We consider the following scenario. A tactical network is sent missions sequentially from a central command and other users with sensing capabilities respond to the mission. We are interested in the set of QoI vectors a network can support, and identifying which of these QoI vectors are most useful in terms of decision making through a utility function. We denote the collection of these utility-maximizing QoI vectors as the *Operational Information Content Sum Capacity (OICC-S)* region of the network. Proposed recently, the notion of *Operational Information Content Capacity* (OICC) is an indicator of the decision making capability that the collection of sources and links, i.e., the network can provide [2]. This is for instance unlike the Network Utility Maximization (NUM) framework where the utility is a function of the flow rates [6]. Although QoI by itself is associated with information generated by a single source, OICC-S captures the interaction of multiple sources or flows and the physical layer they share. We leverage the rather large body of work on capacity of wireless networks in order to determine OICC-S. More specifically, we address the problem of sum utility maximization via optimal rate allocation for cases where some of the QoI attributes are given.

While many different attributes can effect QoI and OICC-S, we particularly focus on the effects of *accuracy* and *timeliness*. Accuracy, generally describing the specificity relative to need of the operation, is an indicator of the initial information content and the success of generating information at the sources. On the other hand, timeliness, which measures the availability of information relative to the time it is needed, is related with success of network delivery. These two attributes possess a trade-off such that improving accuracy degrades timeliness for a given network. In Section IV, we develop a model for QoI utility that depends on these two metrics.

In this paper, we consider the multiple access channel (MAC), with the objective of maximizing the sum utility of the system, i.e., characterizing OICC-S. Main issues we address are obtaining the optimum balance between accuracy and timeliness for the given network, by selecting the *rate point* to allocate. It is well known that max weight scheduling [7] maximizes throughput for this model by operating at one of

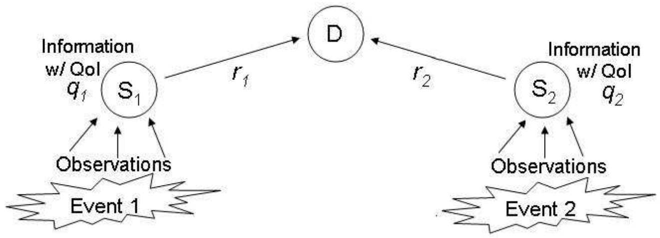

Figure 1. Two-user MAC channel for QoI-based network.

two corner points for the MAC capacity region [8]. In contrast, here, we demonstrate that arbitrary points on the dominant face of the rate region can be optimal rate points to attain OICC-S.

The organization of the paper is as follows. In Sections II, we present the basic model and QoI definitions. Next, in Section III we formally define the OICC-S region. We provide the formulation and give example rate allocation problems to achieve the OICC-S for two different settings with given attributes in Section IV. We provide numerical results in Section V, and conclude the paper in Section VI.

II. System Model

For clarity of exposition, we shall concentrate on two transmitter MAC (Fig. 1). The results can be readily generalized to more than two users. This constitutes a basic and inspiring model for OICC-S characterization, which involve multiuser issues as proper rate allocation between users and QoI vectors accordingly.

We consider a scenario where missions are issued from an end user in a tactical network. Missions arrive stochastically with some minimum interarrival time T_{min}. We assume that at most one mission is processed by the network at any time. Information sources S_1 and S_2 respond to the mission and focus on independent events and possibly possess or generate different types of information related with the mission. This can correspond to separate phenomena related with the environment.

We characterize the overall importance of the information to the mission as the QoI of the piece of information. We note that QoI does *not* say anything about information content: for example, you can have a high-quality image of a blank wall, or a high-quality audio clip of silence. We define two types of QoI:

- *delivered-QoI* is the QoI associated with a piece of information generated and delivered by the network.
- *desired-QoI* is the QoI requested of the network.

Both types of QoI can be represented by a *QoI-vector*, which is a vector of attribute-value pairs: for example, $[type = image,\ timeliness = 10s,\ accuracy = 800 \times 600,\ FOV = 100\, mm\, per\, meter \ldots]$, where FOV is the *field of view* is the is the (angular or linear or areal) extent of the observable world that is seen at any given moment. Here, the linear FOV is given with specified in a ratio of lengths. The first term of accuracy attribute specifies the resolution [2]. A subtle distinction between the two is that a *desired-QoI-vector* may consist of a vector of logical expressions, e.g.: $[type = image,\ timeliness \leq 10s,\ accuracy \leq 1024 \times 768,\ FOV = 100\, mm\, per\, meter, \ldots]$.

Some attributes of QoI vector may be upper bounded due to source capabilities as processing and reception quality. A *QoI-Flow* refers to the transfer of (one piece of) information from a specific source to a specific destination. As a result of network delivery, a delay will be introduced until the information is utilized at the destination. We are interested in the effect of delay due to network delivery on the *timeliness* of the information at the destination. The effects of delivery, more specifically the delays introduced can be characterized by the amount of bits corresponding to the information and the rates of transmitting from sources to the destination.

Sources perform rate allocation and the information contents are delivered to the destination. Once the decision of transmission is made by the sources, the information available is fed into the wireless channel to the destination with a certain rate. The *boundary* of the achievable rate region defines a set of rate pairs (r_1, r_2), which can be assigned to QoI-flows $f1$ and $f2$ respectively, such that any increase to r_1 or r_2 will result in instability. For our two-user model, transmission rates can be upper bounded by the capacity region of a Gaussian multiple access channel given by [9]:

$$r_i \leq W \log_2(1 + \frac{h_i P}{N_0 W}) = c_i, \ i = 1, 2 \quad (1)$$

$$r_1 + r_2 \leq W \log_2(1 + \frac{(h_1 + h_2)P}{N_0 W}) = c_s, \quad (2)$$

where r_i is the rate from S_i to destination, $\sqrt{h_i}$ denotes the channel gain from S_i to the destination node, P is the power constraint for all nodes, the $\frac{N_0}{2}$ is the noise spectral density and $2W$ is the two-sided bandwidth. Channel gains are static throughout a specific mission. We assume that the time scales of interest due to timeliness requirements are large enough, along with a large operational bandwidth, allowing usage of possibly multiple codewords with sufficiently large block lengths to approach the bounds in (1)-(2) during delivery of information from the sources. Essentially, we assume that the available rate options are within a convex pentagonal region (Fig. 2), where two of the corner points correspond to different decoding orders at the destination. The significance of this rate region is that source rates are coupled via the third common constraint in (2). We emphasize that (1)-(2) constitute upper bounds for any practical protocol, as well as transmission schemes with any physical layer coding and modulation scheme.

III. Operational Information Content Sum Capacity (OICC-S)

A. OICC-S Framework

In this framework of OICC-S, there are three steps, illustrated with 2-flow cases. The descriptions will generalize to n flows or m-element QoI-vectors.

We assume the existence of two (discrete) functions:

- one which maps each possible *QoI-vector* to a rate in bits/sec. For example, $[type = image,\ timeliness >$

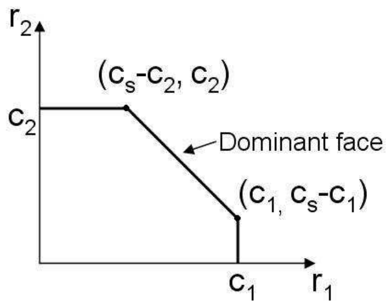

Figure 2. Capacity region for Two-user MAC channel.

$10s$, $accuracy > 1024 \times 768$, $FOV = 100mm\ per\ meter, \ldots]$ may require at least 200 Kbps. We call this function the *QoI-rate function*.

- one which maps each possible *QoI-vector* to a scalar quantity that, for now, we will call *utility*. For example, $[type = image,\ timeliness = 10s,\ accuracy = 1024 \times 768,\ FOV = 100\ mm\ per\ meter, \ldots]$ may have a utility of 10 (on some application-specific scale), but $[type = image,\ timeliness = 5s,\ accuracy = 1024 \times 768,\ FOV = 100\,mm\,per\,meter, \ldots]$ may have a utility of 20. We call this the *QoI-utility function*.

We further specify these two functions in later sections.

Then the OICC-S of a given network can be derived as follows (for two QoI-flows $f1$ and $f2$):

For each pair (r_1, r_2) on the boundary of the achievable rate region

- let $(\mathbf{q}^1_{f1}, \mathbf{q}^2_{f1}, ...)$ (respectively for flow $f2$) be the set of all QoI-vectors whose rates (obtained from the QoI-rate function) are less than or equal to r_1 (respectively r_2).
- let $\mathbf{q}^j_{f1}$ (respectively $\mathbf{q}^k_{f2}$) be the QoI-vector whose utility is the highest in the set $(\mathbf{q}^1_{f1}, \mathbf{q}^2_{f1}, ...)$ (respectively for $f2$).

Then, the set of all pairs $(\mathbf{q}^j_{f1}, \mathbf{q}^k_{f2})$ is defined to be the OICC-S of the network, for the two flows. Note that this set of all pairs $(\mathbf{q}^j_{f1}, \mathbf{q}^k_{f2})$ can also be equivalently identified as the set of QoI-vectors whose sum utility is the highest among any of the feasible $(\mathbf{q}_{f1}, \mathbf{q}_{f2})$ pairs defined above.

1) Example: Assume that three applications are present in a two-source network requiring:

- $\mathbf{q}_1 = [type = image,\ timeliness > 10s,\ accuracy > 1024 \times 768,\ FOV = 100mm\,per\,meter, \ldots]$ requiring at least 200 Kbps with utility 10
- $\mathbf{q}_2 = [type = image,\ timeliness > 5s,\ accuracy > 1024 \times 768,\ FOV = 100mm\,per\,meter, \ldots]$ requiring at least 400 Kbps with utility 20
- $\mathbf{q}_3 = [type = image,\ timeliness > 8s,\ accuracy > 1024 \times 768,\ FOV = 100mm\,per\,meter, \ldots]$ requiring at least 250 Kbps with utility 13.

Consider the rate region of the network defined by: $r_1 \leq 531\ Kpbs$, $r_2 \leq 324\ Kbps$, $r_1 + r_2 \leq 633\ Kbps$, from parameters $h_1 = 3.5$, $h_2 = 1.5$, $W = 250KHz$, $N_0 = 4 \times 10^{-6} Watts/Hz$ in (1)-(2).

It is readily seen that while it is possible to support set of QoI-vectors $(\mathbf{q}_1, \mathbf{q}_3)$, $(\mathbf{q}_3, \mathbf{q}_1)$ and $(\mathbf{q}_2, \mathbf{q}_1)$ by the network, it is not possible to support the set $(\mathbf{q}_2, \mathbf{q}_3)$. Hence, $(\mathbf{q}_2, \mathbf{q}_3)$ cannot be in the OICC-S.

Next, we compare the utilities of the supported sets of QoI-vectors to determine the OICC-S. While $(\mathbf{q}_1, \mathbf{q}_3)$, $(\mathbf{q}_3, \mathbf{q}_1)$ attain a sum utility of 23, $(\mathbf{q}_2, \mathbf{q}_3)$ attains a sum utility of 30. Hence, $(\mathbf{q}_2, \mathbf{q}_3)$ is on the OICC-S.

IV. OICC-S Formulation

We next provide a OICC-S formulation for a given network. We first note that the framework of OICC-S entitles the QoI-utility and QoI-rate functions. While more specific relations could be specified for these two functions for applications as face recognition, speech recognition, in this work we provide a general formulation that can be applied to various applications. Next, we propose a candidate utility function which reflects the trade-off between accuracy and timeliness. More specifically, consider the following utility function of the form for QoI-vector **q**:

$$u(\mathbf{q}) = ag(t_d), \tag{3}$$

where t_d is the timeliness, i.e. delivery time of $\mathbf{q}$, and a is a scalar capturing the overall instantaneous *accuracy metric* of the resolution and FOV of the information specified by $\mathbf{q}$. $l(a)$ is a function corresponding the amount of bits required to represent information of accuracy metric a. While the exact relationship depends on the type of the information under consideration, a natural assumption is that $l(a)$ is a non-decreasing function of a for a specific type of information. Notice that $t_d \geq \frac{l(a)}{r}$, where r is the rate. This equivalently relates to the QoI-rate function through $r \geq \frac{l(a)}{t_d}$ as a rate requirement to support a QoI-vector **q** with the given attributes. $g(t_d)$ is a degradation function reflecting the reduction in utility due to latency. We can also express (3) in terms of a and r as follows:

$$u_r(a, r) = ag(\frac{l(a)}{r}). \tag{4}$$

A function to reflect the traditional notion of timeliness could have the form that the output utility is preserved when delivered within the timeliness requirements, and reduces after some critical deadline [10]. Note that this differs from strict delay constraints which would reduce utility to zero. Piecewise linear functions can be defined for that goal. However, we rather focus on smooth functions which are twice differentiable and concave within the domain of interest in order to pursue more systematic solution methods. As a utility function approximating the desired property, let us consider:

$$g(t_d) = k(\gamma, D)(1 - e^{\gamma(t_d - D)}), \tag{5}$$

for $t_d \leq D$. Example utility degradation curves depicting the effect of timeliness for some different parameters are illustrated in Fig. 3. Note that the general behavior of the utility function is that it initially stays relatively unchanged for low delivery time and decays to zero as the delivery time approaches D. $D \leq T_{min}$ can be thought as a maximum tolerable delay deadline in which the information is regarded useless afterwards, and the exact behavior of the utility curve

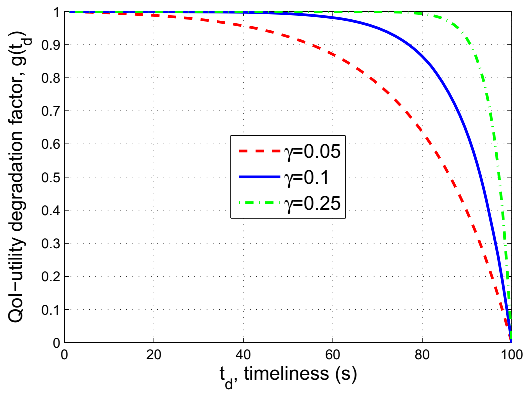

Figure 3. Utility degradation as a function of delivery time, $D = 100s$.

can be adjusted by varying γ. $k(\gamma, D) = \frac{1}{1-e^{-\gamma D}}$ is a normalization parameter.

A. OICC-S Based Rate Allocation

Given a network, it is essential to optimally allocate its resources in order to achieve the OICC-S. To that end, we next formulate a class of optimization problems where one class of attributes are given, and we are interested in rate allocation to achieve QoI-vectors on the OICC-S region. We cast these as sum-utility maximization problems.

1) Accuracy Metrics Given: Consider the special case the following optimization problem defined where a_i, $l_i(a_i)$, $i = 1, 2$, are given:

$$\max_{r_1,r_2} \; a_1k_1(1-e^{\gamma_1(\frac{l_1(a_1)}{r_1}-D_1)})+a_2k_2(1-e^{\gamma_2(\frac{l_2(a_2)}{r_2}-D_2)}) \quad (6)$$

$$\text{s.t.} \quad r_i \le c_i, i = 1, 2 \quad (7)$$

$$r_1 + r_2 \le c_s, \quad (8)$$

where timeliness parameters D_i, γ_i, and constants k_i $i = 1, 2$ are specific to the application. Hence, we are interested in the optimal rate allocation to maximize sum utility, which will in-turn define the timeliness attributes of $\mathbf{q}_{f1}$ and $\mathbf{q}_{f2}$. In order to assess the applicability of standard optimization methods, we check for concavity:

$$\frac{\partial u_r(a, r)}{\partial r} = k\gamma a \frac{\gamma l(a)}{r^2} e^{\gamma(\frac{l(a)}{r}-D)}, \quad (9)$$

Next,

$$\frac{\partial^2 u_r(a, r)}{\partial r^2} = kal(a)\gamma[\frac{-2}{r^3} - \frac{-\gamma l(a)}{r^4}]e^{\gamma(\frac{l(a)}{r}-D)} \quad (10)$$

$$< \quad 0. \quad (11)$$

Hence the utility function is concave in rate r. We also note that the feasible region for r (MAC rate region) is a convex set.

Theorem 1: Given accuracy metrics (a_1, a_2) of QoI-flows, the optimal rate allocation (r_1^*, r_2^*) is given by one of:

1) $(r_1, r_2) = (c_1, c_s - c_1)$
2) $(r_1, r_2) = (c_s - c_2, c_2)$
3) (r_1, r_2) on dominant face $(r_1 + r_2 = c_s)$ with:

$$\frac{r_1^2}{r_2^2} = \frac{k_1\gamma_1^2 a_1}{k_2\gamma_2^2 a_2} \frac{e^{\gamma_2(\frac{l_2(a_2)}{r_2}-D_2)}}{e^{\gamma_1(\frac{l_1(a_1)}{r_1}-D_1)}}, \quad (12)$$

and the exact operating point solution can be determined by evaluating the total output QoI utilities. Moreover, timeliness attributes attaining the OICC-S are given by $t_{di}^* = \frac{l_i(a_i)}{r_i^*}$, for $i = 1, 2$.

Proof: Let us introduce Lagrange multipliers $\lambda_1, \lambda_2, \lambda_3$, all greater than or equal to 0, for constraints (7)-(8). The Lagrangian can be expressed as:

$$L(r_1, r_2, \lambda_1, \lambda_2, \lambda_3) = -\sum_{i=1}^{2} a_ik_i(1 - e^{\gamma_i(\frac{l_i(a_i)}{r_i}-D_i)})$$

$$+\sum_{i=1}^{2} \lambda_i(r_i - c_i) + \lambda_3(r_1 + r_2 - c_s). \quad (13)$$

Karush-Kuhn-Tucker (KKT) conditions dictate:

$$-k_i\gamma_i a_i \frac{\gamma_i l_i(a_i)}{r_i^2} e^{\gamma_i(\frac{l_i(a_i)}{r_i}-D_i)} + \lambda_i + \lambda_3 = 0, \quad (14)$$

$$\lambda_i(r_i - c_i) = 0, \; i = 1, 2 \quad (15)$$

$$\lambda_3(r_1 + r_2 - c_s) = 0. \quad (16)$$

Hence we have:

$$k_i\gamma_i a_i \frac{\gamma_i l_i(a_i)}{r_i^2} e^{\gamma_i(\frac{l_i(a_i)}{r_i}-D_i)} = \lambda_i + \lambda_3, i = 1, 2 \quad (17)$$

Note that these imply that $\lambda_1 + \lambda_3 > 0$ and $\lambda_2 + \lambda_3 > 0$. First, assume $\lambda_3 = 0$. Than, $r_1 + r_2 < c_s$ and $\lambda_1 > 0$, $\lambda_2 > 0$ should be satisfied leading to $r_1 = c_1$, $r_2 = c_2$ but this combination is not feasible ($c_s < c_1 + c_2$). Hence it is required that $\lambda_3 > 0$, and accordingly we have $r_1 + r_2 = c_s$.

As for λ_1 and λ_2, we have the option that only one of them is positive, which would correspond to one of the corner points of the rate region. The other option is that when $\lambda_1 = \lambda_2 = 0$, which implies that $r_1 < c_1$ and $r_2 < c_2$. Along with $r_1 + r_2 = c_s$, this results in an operating point on the dominant face of the rate region (which is achieved by strict time sharing between the two corner points corresponding to different decoding order at the receiver). From (17), with $\lambda_1 = \lambda_2 = 0$ we have

$$k_1\gamma_1^2 a_1 \frac{l_1(a_1)}{r_1^2} e^{\gamma_1(\frac{l_1(a_1)}{r_1}-D_1)} = k_2\gamma_2^2 a_2 \frac{l_2(a_2)}{r_2^2} e^{\gamma_2(\frac{l_2(a_2)}{r_2}-D_2)} \quad (18)$$

leading to equation (12). In other words, the operating point is the point on the dominant face satisfying (12). The specific point will depend on multiple parameters, including accuracy attributes and timeliness parameters. ■

2) Timeliness Attributes Given: Next, we consider the rate allocation problem where timeliness attributes of $(\mathbf{q}_{f1}, \mathbf{q}_{f2})$ are given. This may correspond to delay-critical applications. In other words, we consider the problem (6) with t_{di}, $i = 1, 2$, are given instead of a_i. Through the relation $\frac{l_i(a_i)}{r_i} = t_{di}$, we convert it to the following problem:

$$\max_{r_1,r_2} \quad l_1^{-1}(r_1 t_{d1}) k_1 (1-e^{\gamma_1(t_{d_1}-D_1)})$$
$$+l_2^{-1}(r_2 t_{d2}) k_2 (1-e^{\gamma_2(t_{d2}-D_2)}) \tag{19}$$
$$\text{s.t.} \quad r_i \leq c_i, i=1,2 \tag{20}$$
$$r_1 + r_2 \leq c_s, \tag{21}$$

where timeliness parameters D_i, γ_i, and constants k_i $i = 1,2$ are specific to the application. Note that this expression hinges on the existence of the inverse of the function $l_i(a)$, i.e., $l(a)$ is a one-to-one function of a for a given type of information.

For the special case where $l_i(a_i) = a_i$, the objective of (19) takes the following form:

$$r_1 t_{d1} g_1(t_{d_1}) + r_2 t_{d2} g_2(t_{d2}). \tag{22}$$

The solution is readily given by the following rule:

Proposition 1: Given attributes (t_{d1}, t_{d2}), with $l(a) = a$, the optimal rate pair (r_1^*, r_2^*) is given by:

$$(r_1, r_2) = \begin{cases} (c_1, c_s - c_1), & \text{if } t_{d1} g_1(t_{d_1}) > t_{d2} g_2(t_{d_2}) \\ (c_s - c_2, c_2), & \text{if } t_{d1} g_1(t_{d_1}) < t_{d2} g_2(t_{d_2}) \end{cases} \tag{23}$$

Moreover, (a_1, a_2) of $\mathbf{q}_{f1}, \mathbf{q}_{f2}$ are given by $l_i(a_i) = r_i^* t_{di}$, $i = 1,2$.

V. Numerical Results

Next, we demonstrate that optimal rate allocation can be different from a corner point of the rate region for various scenarios.

First, consider the scenario with information types, QoI-vectors, timeliness properties, link qualities and device capabilities characterized by parameters $\gamma_1 = 0.1$, $\gamma_2 = 0.05$, $D_1 = 10s$, $D_2 = 15s$, $c_1 = 212Kbps$, $c_2 = 142Kbps$, $c_s = 259Kbps$. We assume that $l_i(a_i) = a_i \times 10^5$, for $i = 1,2$ and $a_2 = 5$. We observe the effect of varying a_1 on optimal rate allocation and the sum utilities for the MAC in Fig. 4 and Fig. 5.

We see that the optimal rate allocation greatly differs depending on a_1. For small a_1, strict priority is given to user 2, which has a higher accuracy. As a_1 increases, timesharing between two corner points is selected. Further increase in a_1 results in strict priority to user 1 due to its higher impact on utility. However, eventually increase in accuracy for source 1 results in significant degradation of utility due to untimeliness, and priority is again switched to source 2.

Hence, in many scenarios a simplified policy only focusing on corner points could not have provided the network with the maximum utility, i.e., attained OICC-S for the available information at hand or equivalently decision making capability.

Next, we consider a case with identical parameters except $l(a) = \alpha a^3$, where $\alpha = 4 \times 10^3$. This corresponds to a case where accuracy metric is a concave function of the number of bits required. The intuition is that utility gains are diminishing in return; after some level the accuracy metric and the effect to utility tends to saturate. As seen in Fig. 6 and Fig. 7, even though the general behavior of rate allocation is similar

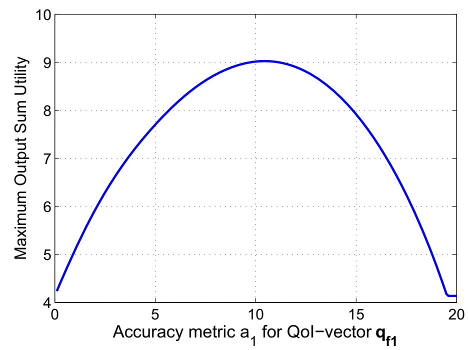

Figure 4. Maximum Sum Utilities for varying a_1.

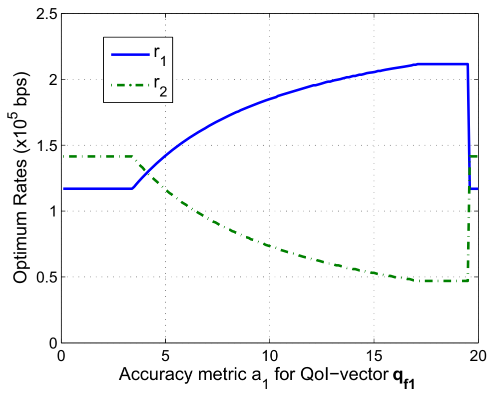

Figure 5. Optimal rates for QoI-flows for varying a_1.

to the previous case, it is observed that excessive delivery requirements for high-accuracy information penalizes source 1 for lower accuracy metrics compared with the previous case where $l(a)$ is directly proportional to a.

We also demonstrate the results for various given timeliness attribute requirements for desired-QoI vectors, with $l_i(a_i) = a_i \times 10^5$, $i = 1,2$. We fix $t_{d1} = 7s$, that is 70 percent of its expiration deadline, and t_{d2} varies until its expiration time $D_2 = 15s$. Observing Fig. 8, we see that with too stringent timeliness requirements, the input information quality that can be delivered is limited, hence resulting in low accuracy attributes and sum utility. As timeliness requirements are relaxed, information with higher accuracy can be delivered, increasing OICC-S. As timeliness requirements become too loose and t_{d2} approaches D_2, utility decays due to large degradation factor.

Similarly, for the optimal rate allocation, we observe that priority is switched to second source only when its impact to sum utility can be large due to sufficient accuracy and timeliness attributes which do not suffer significant degradation. This corresponds to the medium timeliness region in Fig. 9. For either too strict or too loose timeliness attribute requirements on desired-QoI, resource is allocated to the other QoI-flow $\mathbf{q}_{f1}$. It is readily seen that rate allocation is one of the two corner points as specified by (23) for this setting.

VI. Conclusions

In this paper, we propose methods for QoI based utility evaluation in multisource networks. We characterize the QoI-

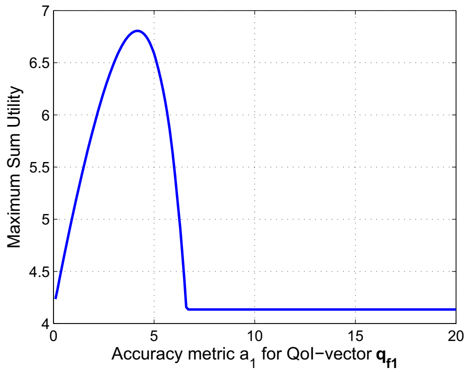

Figure 6. Maximum Sum Utilities for varying a_1, $l(a) = \alpha a^3$.

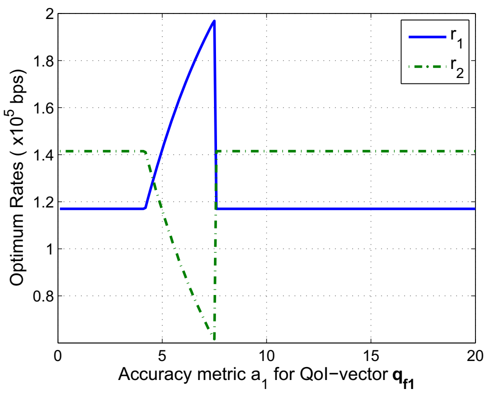

Figure 7. Optimal rates for QoI-flows for varying a_1, $l(a) = \alpha a^3$.

vectors which are supportable and maximize the sum output utility provided by the network as the OICC-S. For OICC-S formulation, we focus on the effect of network delivery and timeliness on information with specific accuracy. We characterize rate allocation schemes in order to attain OICC-S for the most basic multiuser network model, specifically a two-user MAC. The formulations provided can be generalized to account for other QoI-attributes which inherent similar trade-offs.

While we have focused on a two-user MAC in this work, we note that similar principles can also be used to determine rate allocation for a two-user broadcast channel. Future work includes extension of the policies for general multihop networks, and policies addressing random observation arrivals. Furthermore, generalizing the framework to allow for correlated events and node capabilities as compression is of interest.

VII. Acknowledgement

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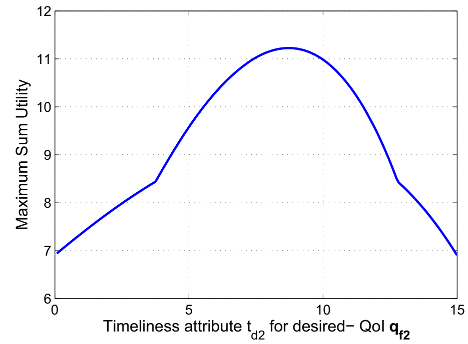

Figure 8. Maximum Sum Utilities for varying t_{d2}.

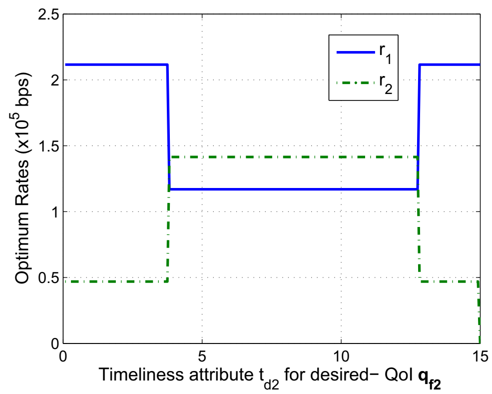

Figure 9. Optimal rates for QoI-flows for varying t_{d2}.

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